Technical Memo

ANL/EES-TM-303

DISAGGREGATION OF INDUSTRIAL FOSSIL FUEL USE IN THE 1985 NATIONAL ENERGY POLICY PLAN: METHODOLOGY AND RESULTS

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ARGONNE NATIONAL LABORATORY

Energy and Environmental Systems Division

Operated by

THE UNIVERSITY OF CHICAGO for U. S. DEPARTMENT OF ENERGY

under Contract W-31-109-Eng-38

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Printed in the United States of America. Available from National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

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9700 South Cass Avenue, Argonne, Illinois 60439

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Energy and Environmental Systems Division
Argonne Energy-Economic Modeling Program

June 1985
(revised January 1986)

work sponsored by

U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Fossil Energy
Office of Planning and Environment

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FOREWORD

Under the auspices of the National Acid Precipitation Assessment Program (NAPAP), activities supporting the preparation of future assessments have been planned and delegated to task groups. Task Group B (TG-B), "Man-Made Sources" (subsequently redesignated Task Group I, "Emissions and Controls"), of the Interagency Task Force on Acid Precipitation is responsible for developing and testing models that can be used to project fuel use and air pollutant emissions by energy use sector. Argonne has participated in the TG-B program since 1984.

The TG-B program is being carried out in two phases. Phase 1 includes development of the models for generation of baseline scenarios. Phase 2 will address the capabilities for modeling emission control scenarios. Under Phase 1, the sector models are being developed and tested. This testing is designed to aid in model development and help prepare the models for use by the task force. Upon completion, the sector models will be incorporated into the TG-B emissions model set and linked to a system of models that provide scenario-consistent input data.

The Argonne Energy-Economic Modeling Program is publishing a series of reports that document the steps undertaken to prepare national and regional projections of energy and economic activity required as input to the sector emissions models. This report is part of this series; it documents the procedures followed to generate national projections of industrial fossil fuel use in boilers by Standard Industrial Classification code. For the test runs conducted under Phase 1, these national projections are disaggregated from total industrial use of fossil fuel as reported in the 1985 National Energy Policy Plan (NEPP-85). This disaggregation procedure, however, can be calibrated to any national forecast of total industrial energy use. The output from the disaggregation is used as a control total in the Argonne Regionalization Activity Module (ARAM). ARAM systematically translates national control forecasts into the regionalized driver data needed to operate each sector emissions model. Separate methodology documents describe the regionalization activities for each sector model.

ACKNOWLEDGMENTS

The authors would like to acknowledge the helpful comments supplied by reviewers in the Office of Fossil Energy and the Energy Information Administration of the U.S. Department of Energy; and the management support and guidance of H. William Hochheiser, our project manager in the Office of Fossil Energy. Any errors or omissions remain the responsibility of the authors.

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SUMMARY

The methodology described here projects use of purchased boiler fuel from 1980 to 2030 for six industrial groups. Three types of information were required to generate these projections: a long-term forecast of total industrial fossil fuel use, forecasts of industrial activity, and relative growth rates of industrial energy intensity. The resulting projections were used as inputs to the Industrial Combustion Emissions (ICE) model, one of the sector models of the National Acid Precipitation Assessment Program.

In our projections, we used long-term forecasts of fossil fuel use from the 1985 National Energy Policy Plan (NEPP) prepared by the U.S. Department of Energy (DOE). The NEPP provides projections of total industrial energy use from 1980 to 2010 for several fuel types and three economic growth scenarios (base, low, and high). To extend these projections to 2030, total energy use, electricity use, and renewable energy use were extrapolated. Fossil fuel use was determined by subtracting electricity and renewable energy use from total fuel use.* This method assumes that trends in electrification and renewable technology penetration will continue after 2010. In the NEPP, these two energy sources are predicted to replace the fossil fuels that would otherwise have been used to meet industrial energy requirements. Because of these optimistic forecasts of electrification and renewable technology penetration, long-term forecasts of fossil fuel use show little or no growth.

Because energy use in a specific industry depends on corresponding growth in industrial activity, our forecasts of industrial activity came from Data Resources Inc. (DRI) forecasts of Federal Reserve Board (FRB) production indexes for specific industries. The DRI forecast for the base case was commissioned by DOE specifically for the NEPP base case. The DRI low case corresponds to the NEPP low case. We constructed our own forecast of FRB production indexes that corresponded to the NEPP high case.

We constructed relative rates of growth for energy intensity in each industry group from historical data. Energy use by industry is not proportional to industrial activity because each industry has different incentives and propensities to conserve (or

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*Some judgment was exercised in this extrapolation. Because no clear trend was apparent in fossil fuel use but trends were discernable in electricity, renewable, and total energy use, fossil fuel use was projected as a residual.

use) energy. Thus two adjustment factors for each industry were constructed and applied to the forecast of industrial activity growth. The first adjustment accounts for different rates of change in energy intensity between industries (i.e., either conservation or increases in energy intensity). The second adjustment corrects a bias in the FRB index for three energy-intensive industries (paper, chemicals, and primary metals). Adding the growth rate in industrial activity and the two adjustment factors yields the relative rate of energy intensity growth for an industry.

Combining the three elements -- fossil fuel use, industrial activity, and relative growth rate of energy intensity -- yields a disaggregation of total purchased fossil fuel for each industry consistent with the NEPP forecast. Total fossil fuel use is then converted to boiler fuel use by applying some conversion factors constructed from 1980 census data and 1980 ICE model data. The results indicate negligible growth in boiler fuel use for most of the six industries represented in detail in the ICE model. Only the chemical industry has any significant growth in boiler fuel use in the base and high cases. This finding reflects (1) the low growth in fossil fuel use projected by the NEPP, (2) optimistic projections for the chemical industry by DRI, and (3) significant conservation rates in the other industries.

1 INTRODUCTION

In the National Acid Precipitation Assessment Program (NAPAP), Task Group B (TG-B) is responsible for developing and testing models that can be used to project fuel use and air pollutant emissions by energy use sector. As discussed in the foreword, this work is being carried out in two phases. All activities described in this report have taken place under Phase 1 of the TG-B program. This report addresses one aspect of the system designed to supply energy-economic driver data to the TG-B emissions model set (see Fig. 1): provision of disaggregated projections of industrial fossil fuel use. The following sections provide additional background and organization for the report.

1.1 BACKGROUND AND PURPOSE

The sector models in the TG-B emissions model set represent a unique set of models. They also each have a distinctive set of input requirements. These input data, also called driver data, are not always directly available from energy and economic forecasting models operating in the public or private domain. To overcome this problem, a procedure was designed to translate available energy and economic projections into the

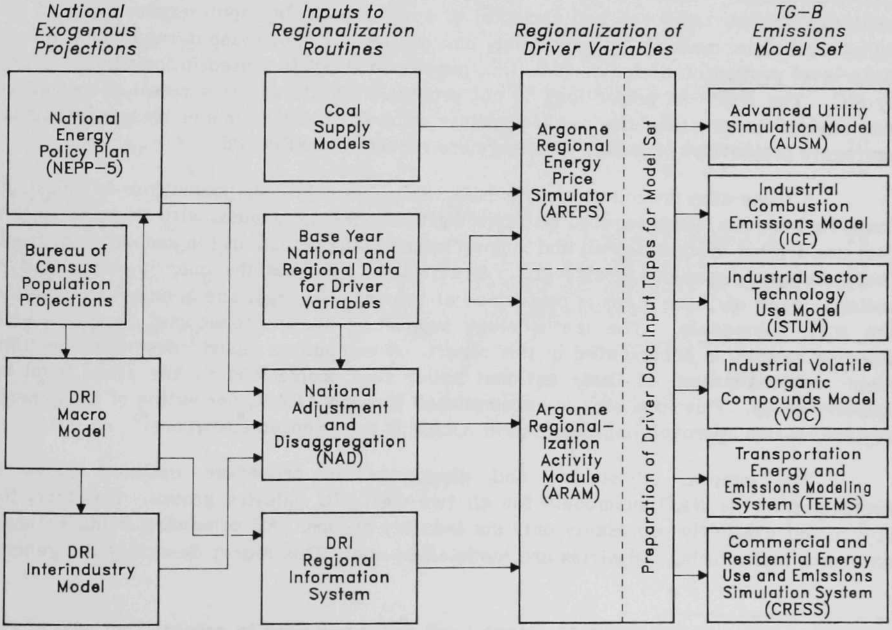

FIGURE 1 Block Diagram of the Energy-Economic Driver Module

driver data necessary to operate each sector emissions model. This procedure is implemented in the Energy-Economic Driver Module diagramed in Fig. 1. Exogenous national projections are adjusted and disaggregated into the inputs required by the regionalization routines. These routines then systematically generate the required input data for each sector model. Several submodules make up the Energy-Economic Driver Module.[1] Although development of the driver module was distinct from development of the sector models, the system is fully integrated in the TG-B emissions model set.[2]

This report describes the specific steps undertaken to provide national projections of industrial fossil fuel use by Standard Industrial Classification (SIC) code to the Argonne Regionalization Activity Module (ARAM). ARAM uses these national projections as control totals in generating the requisite driver data for the Industrial Combustion Emissions (ICE) model, one of the sector models in the TG-B emissions model set. A separate report describes the ARAM methodology and driver data generated for the ICE model,[3] whereas this report documents those activities associated with preparing national control totals. These activities comprise the National Adjustment and Disaggregation (NAD) submodule identified in Fig. 1. A summary of why such NAD activities are required to prepare the ICE model driver data is provided below.

It was a requirement that all driver data activities taking place under Phase 1 of the TG-B program be based on projections contained in the 1985 National Energy Policy Plan (NEPP-85).* However, these NEPP-85 projections do not have sufficient detail (sectoral, spatial, temporal, and variable) to comply with the input requirements of the sector emissions models. In particular, one of the ICE model input requirements is a state-level projection of boiler fuel (i.e., purchased fossil fuel used in industrial boilers) by SIC. The NEPP-85 projections do not provide these data. As a result, a procedure was devised to generate the required driver data for the ICE model by using national aggregate projections of industrial energy use reported in NEPP-85.

A three-step procedure was devised. First, the NEPP-85 projections of industrial fossil fuel use are disaggregated into two-digit SIC industry groups, with their respective fuel use divided into purchased and nonpurchased components. In the second step, fossil fuel purchased by each industry group is adjusted to reflect the quantity consumed in boilers. Each of these steps is performed at the national level and accomplished within the NAD submodule. The methodology supporting these procedures, together with selected results, is documented in this report. A companion report[3] describes the third step: regionalization of these national boiler fuel projections to the state level by industry group. This final step is accomplished through ARAM; derivation of the general regionalization approach implemented in ARAM is documented elsewhere.[5]

The general adjustment and disaggregation procedure outlined above is performed in the NAD submodule for all two-digit SIC industry groups. However, the ICE model explicitly represents only six industry groups. All remaining manufacturing and nonmanufacturing industries are modeled as one. This report describes the general

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*A draft version of the NEPP-85, dated April 1985, was used to prepare test runs of the driver data.[4] Subsequent references to NEPP-85 correspond to these draft projections and not the final NEPP-85 projections.

procedures followed for all industry groups, but specifically focuses on those industries considered in the ICE model. The industrial sectors considered in the ICE model, and hence analyzed in detail here, are shown in Table 1. The six industries identified in Table 1 consume the largest quantities of boiler fuel in the industrial sector. These industries can also be segmented by their degree of energy intensity: Group 2 is very energy intensive while Group 1 is relatively less so (although it still has some subsectors with high energy intensity). In 1980, these six industries account for the bulk (74.5%) of the fuel consumed by all manufacturing industries (9.23 quads).*

1.2 ORGANIZATION OF THE REPORT

Section 2 of this report presents an overview of the industrial energy projections in the NEPP-85, including industrial fossil fuel demand and electricity demand. The sector-specific adjustments to industrial growth used to obtain the relative growth rates of energy demand are presented in Sec. 3. These adjusted growth rates provide the basis for the disaggregation methodology described in Sec. 4. Section 4 documents the methodology used to project boiler fossil fuel use at the national level by industry group; the methodology is based on NEPP-85 projections of industrial fuel use and relative growth rates calculated in Sec. 3. The resulting projections of boiler fuel use, by scenario, are reported and described in Sec. 5. Appendix A presents the econometric estimation of energy-intensity growth rates and the impact of capacity utilization considered in Sec. 3. Appendix B reports the generation of industrial production indexes for a high-economic-growth scenario for use in this application (industrial production indexes for low and reference scenarios were provided by Data Resources, Inc.).

TABLE 1 Principal Industrial Sectors Considered

Industry	SIC
Group 1	
Food and kindred product	20
Textile mill products	22
Group 2	
Paper and allied products	26
Chemicals and allied products	28
Petroleum and coal products	29
Primary metals (total)	33

*1 quad = 10^{15} Btu.

2 NATIONAL CONTROL FORECASTS OF INDUSTRIAL ENERGY USE

This section provides an overview of some relevant projections from NEPP-85. These projections are the basis for the driver data developed as part of Phase 1 activities to test the sector models of the TG-B emissions model set. That is, NEPP-85 projections provide national control totals for key aggregate energy variables. The inputs to the sector emissions models are linked to NEPP-85 aggregate energy variables through one or more of the Energy-Economic Driver submodules (see Fig. 1). The industrial energy use projections in the NEPP-85 are the principal focus here.

2.1 MACROECONOMIC PROJECTIONS

Three economic growth scenarios are considered in the NEPP-85: U.S. Department of Energy (DOE) reference, low, and high scenarios. Gross national product (GNP) values (in 1984 real dollars) and average annual growth rates between 1980 and 2030 are presented in Table 2 for each economic scenario. The GNP values for the period 1980-2010 are reported as part of the NEPP-85. A long-term extension (2010-2030) of these macroeconomic projections was prepared by Data Resources, Inc. (DRI).[6] Figure 2 illustrates the patterns of GNP growth by scenario. In summary, the GNP growth rates from 1984 to 2010 are 2.05%, 2.64%, and 3.14% for the low, reference, and high scenarios, respectively. Note that the low and high scenarios bound the reference scenario.

2.2 INDUSTRIAL PROJECTIONS

As indicated, the focus of this report is the industrial sector. Therefore, this section deals only with industrial sector projections contained in the NEPP-85. These projections do not include nonenergy feedstocks. Total industrial energy use (excluding feedstocks) from the NEPP-85 and its long-term extension to the year 2030 are depicted in Fig. 3 by scenario.

According to Fig. 3, the industrial sector consumed about 20.3 quads in 1980. Consumption declined to 18.4 quads in 1984. Thereafter, industrial energy use rises rapidly, especially between 1984 and 1990, a period with projections of higher GNP growth and lower oil prices. After 1990, industrial energy use increases linearly, with energy use quite sensitive to the different economic growth rates between scenarios. By the year 2000, industrial energy use (excluding feedstocks) is 21.1, 24.8, and 27.3 quads for the low, reference, and high scenarios, respectively.

Figure 4 shows industrial electricity demand by scenario. These projections exclude electricity generated by industry. Electricity is expected to continue to penetrate the industrial sector at a rapid rate, particularly in the reference and high scenarios. To obtain end-use electricity demand, industrial cogeneration must be added. The WOIL/FOSSIL2 model, used by DOE for its NEPP, projects generation by both electric utilities and industry. This report addresses the procedures employed to produce

TABLE 2 Projections of Gross National Product Underlying the Three NEPP-85 Scenarios[a]

Year	Real GNP Levels by Scenario (10^9 1984 $)			Average Annual Growth Rate by Scenario (%)		
	Low	Ref.	High	Low	Ref.	High
Historical						
1980	-	3,285	-	-	-	
1984	-	3,675	-	-	2.84	
Projected						
1990	4,248	4,584	4,692	2.44	3.75	4.16
1995	4,690	5,123	5,400	2.00	2.25	2.85
2000	5,125	5,745	6,206	1.79	2.32	2.82
2005	5,642	6,440	7,135	1.94	2.31	2.83
2010	6,236	7,235	8,218	2.02	2.36	2.87
Long-term macroeconomic extension[b,c]						
2015	6,786	8,079	9,357	1.70	2.23	2.63
2020	7,266	8,787	10,326	1.38	1.69	1.99
2025	7,786	9,551	11,334	1.39	1.68	1.88
2030	8,342	10,363	12,361	1.39	1.65	1.75

[a]GNP projections for 1984-2010 are taken from NEPP-85,[4] while those for 2010-2030 were prepared by DRI.[6] The DRI projections for the period 1984-2010 are reported in Table B.1. Some negligible differences in the GNP growth rates exist during this time period because DRI could not exactly replicate the GNP growth path in NEPP-85 with its macroeconomic model.

[b]DRI forecasts for the reference and low scenarios are converted from 1972 to 1984 dollars with the GNP price deflator, estimated by DRI to be 2.23.

[c]The difference in GNP growth rates between the high and reference scenarios is tapered for the long-term extension of the high scenario. The difference in growth rates is 0.5% in the 2005-2010 period and 0.4, 0.3, 0.2, and 0.1% respectively in the next four periods. This results in (roughly) a symmetric difference when the low and high scenarios are compared with the reference scenario. For example, in the year 2030, the high and low scenarios each differ from the reference scenario by about $\$2 \times 10^{12}$.

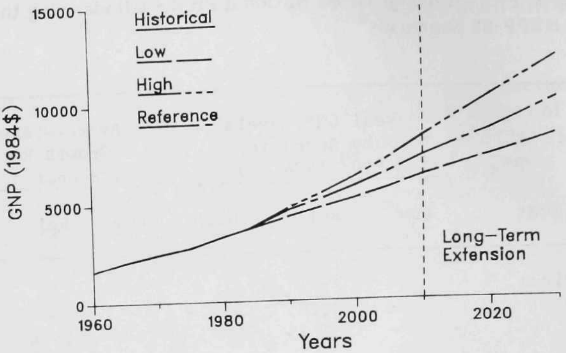

FIGURE 2 Paths of Economic Growth: Comparison of Three NEPP-85 Scenarios

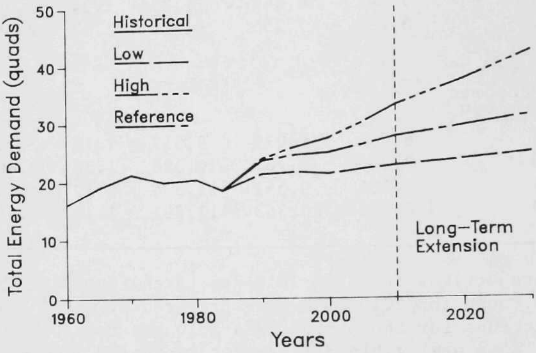

FIGURE 3 Total Industrial Energy Demand (excluding nonenergy feedstocks), by Scenario, from NEPP-85

national projections of end-use electricity demand by industrial sector. The calculation of end-use electricity demand by sector and its regionalization to the state level, for use in the electric utility model in the TG-B model set, is documented in Ref. 7.

Industrial demand for energy from dispersed renewable sources is illustrated in Fig. 5. These renewable sources include biomass, urban solid waste, industrial hydropower, industrial process heat from active solar sources, and geothermal energy. The NEPP-85 presents a promising outlook for these dispersed renewable technologies in the industrial sector.

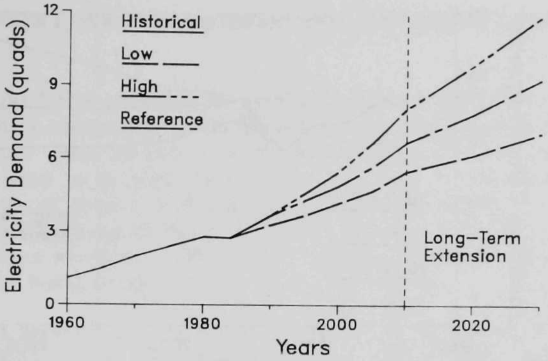

FIGURE 4 Industrial Electricity Demand, by Scenario, from NEPP-85

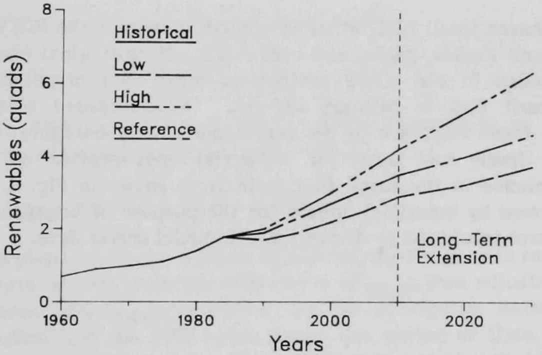

FIGURE 5 Renewable Energy Demand in the Industrial Sector, from NEPP-85

Industrial fossil fuel use, a subset of total industrial energy use, is depicted in Fig. 6. Fossil fuel use, like total industrial energy use, rises rapidly from 1984 to 1990. After 1990, fossil fuel use rises in the high scenario but actually falls in the reference and low scenarios. This projected decline occurs because rapid growth in industrial electricity and renewables, when subtracted from total industrial energy use, leads to a reduction in fossil fuel use in the reference and low scenarios.

The projection of industrial fossil fuel demand in the NEPP-85 is of primary interest in this report because it provides the starting point for calculation of boiler

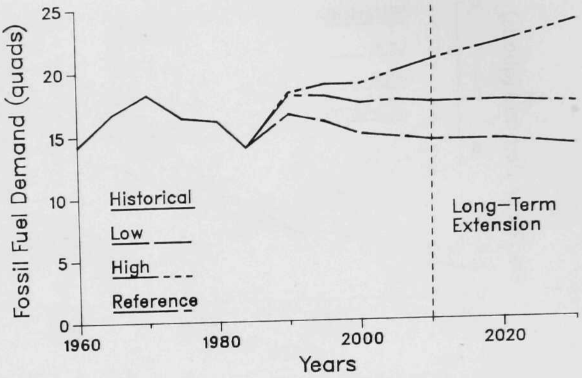

FIGURE 6 Industrial Fossil Fuel Demand, by Scenario, from NEPP-85

demand for purchased fossil fuel, which is needed to operate the ICE model.* Fossil fuel demand includes all liquids, gases, and coal solids. Metallurgical coal and nonpurchased fossil fuel, included in the NEPP projection, must be subtracted. An example of nonpurchased fossil fuel is refinery off-gas. Nonpurchased biomass fuels can be neglected, since these fuels are in the renewable energy category. Also, it should be noted that the fossil fuel used for industrial cogeneration or self-generation of electricity is included in the fossil fuel projections shown in Fig. 6. Hence, purchased fossil fuel consumed by industrial boilers for the purpose of cogeneration is included in the national control total used to derive the ICE model driver data.

*The ICE model is restricted to boiler demand for purchased fossil fuel in all six industrial sectors except petroleum refineries (SIC 29). In SIC 29, residual fuel oil produced at the refinery and consumed in its boilers is also considered by the ICE model. Otherwise, all nonpurchased (or interplant transfers of) by-product fuels such as blast furnace or coke over-gas, refinery off-gas, wood wastes, and hydrocarbon feed-stocks are not considered in the ICE model.

3 INDUSTRY-SPECIFIC RATES OF RELATIVE ENERGY GROWTH

Although the NEPP provides the overall rate of energy growth in the industrial sector, it is necessary to account for the differential rates of industry growth and energy use or conservation. This section presents the conceptual model and the historical analysis that are used to project these rates. As such, it discusses the process of determining the rate of change in energy use, by industrial sector, from a projection of industrial activity. This procedure incorporates (1) the rate of change in energy intensity and (2) an adjustment to reflect differences between physical levels of production and the Federal Reserve Board (FRB) index of industrial production.

Section 3.1 provides an overview of the procedure while Secs. 3.2 and 3.3 provide a detailed description of each component of the conceptual model. A forecast based on the procedure is presented in Sec. 3.4, and a summary is contained in Sec. 3.5.

3.1 OVERVIEW OF PROCEDURE

Energy use in a sector, E, is given by the identity

$$E = I_{FRB} \times (Q/I_{FRB}) \times (E/Q) \tag{1}$$

where I_{FRB} is the FRB index of industrial production and Q is an index of physical production. In terms of growth rates, r, we thus have

$$r(E) = r(I_{FRB}) + r(Q/I_{FRB}) + r(E/Q) \tag{2}$$

Equation 2 yields a simple method of forecasting the growth rate of energy, r(E). Given a forecast rate of growth in the FRB index, $r(I_{FRB})$, two adjustments are applied. The first adjustment, $r(Q/I_{FRB})$, accounts for the divergence between the physical measure of production and the FRB index during any period of time. For a particular industry, this adjustment may be zero if the FRB index represents physical production trends well. The second adjustment, r(E/Q), accounts for changes in energy productivity or the penetration of a particular energy type (e.g., electricity) due to fuel substitution and new energy-using processes. Therefore, this adjustment may be negative or positive and may also vary over time. Historical and projected values for each of these adjustments are discussed in the remainder of this section, together with the basis for these adjustments and the procedures for computing their values.

There are two main reasons for the decomposition of energy use per unit of value added, as cited in Eq. 2. The first is accuracy. In some sectors, detailed data are available from which estimates of r(E/Q) have been made. The second reason is forecasting. Either of the two adjustments in Eq. 2 may vary over time. Since they have different interpretations and causes, as well as effects, they must be modeled and forecasted separately. For example, one adjustment may remain constant while the other may decline.

The FRB industrial production index and its growth rate are projected by DRI. For this work, the DRI projections of production are taken as given.* In this report the two adjustment terms in Eq. 2 are estimated from historic trends. In preparing an industrial energy outlook, these growth rate adjustments are assumed to be stable, at least for midrange projections. The interpretation of these growth rates is discussed in Sec. 3.4.

On the basis of historical evidence, the adjustments to the growth rate of the FRB index, $r(Q/I_{FRB})$, are discussed below (Sec. 3.2), while estimates of changes in energy intensity, $r(E/Q)$, are covered in Sec. 3.3. Section 3.4 contains forecasts based on these historical results.

3.2 DETERMINING AN APPROPRIATE MEASURE OF INDUSTRIAL PRODUCTION

This section begins by discussing FRB production indexes. Then, the selection of physical measures of production, Q, is addressed. A forecast of their behavior relative to the FRB index is presented in Sec. 3.2.3.

3.2.1 FRB Production Indexes

Many models of the U.S. economy, such as that developed by DRI, rely on historical data in the form of value-added weighted indexes. The preeminent family of such indexes is published by the Board of Governors of the Federal Reserve System. The FRB indexes of industrial production are constructed by dividing industry both horizontally and vertically into highly specific subsectors, i; giving each a fixed weight, $W_{VA,i}$, proportional to the value added in that subsector (as of 1967 in current indexes); and describing change in each subsector by means of a production time series, $P_i(t)$. [$P_i(t)$ is normalized to 100 in the base year.] The index for any group of subsectors is then

$$I(t) = \sum_i W_{VA,i} P_i(t) / \sum_i W_{VA,i} \tag{3}$$

The index is thus proportional to the real value that would have been added at actual production levels, had the value added per unit of production remained constant in time. This value-added construction avoids double counting among subsectors.

For many subsectors the production time series $P_i(t)$ are simple physical measures of production that are available on a regular basis and do not require elaborate manipulation before use. One important aspect of the FRB indexes is their quick publication (monthly). Other aspects are their systematic coverage of all industrial sectors and consistent publication over a period of decades. As a result, FRB production indexes are widely used and are often what is meant in forecasts by the term "production."

*The DRI projections were evaluated to determine their reasonableness.[8]

Unfortunately, the two-digit SIC indexes prepared by the FRB may not be the best measure of industrial activity for energy forecasting. For our purposes, a measure of production to which energy use would be proportional is desired [excluding technical change and effects associated with varying capacity utilization, both of which are captured in r(E/Q) -- see Sec. 3.3]. There are two problems in relating the FRB index to energy usage:

- *Shift in Output Mix.* Within two-digit SICs, energy-intensive activity often has been growing at a slower rate than overall activity.[9] For example, the production of basic high-volume chemicals is growing more slowly than downstream production activities like the creation of highly fabricated and highly refined products.

- *Choice of Representative Product Measures.* Activity in sectors that include many highly differentiated products is hard to measure. The measure chosen by the FRB is, in some scenarios, inappropriate for energy analysis. For example, basic organic chemicals production has been determined by kilowatt-hours of electricity consumed in those plants primarily devoted to basic organics.

Marlay[10] points out another feature of the FRB index that exacerbates the concerns noted above. The FRB index is computed on the basis of a small number of representative products, which, if growing faster (slower) than those omitted, contribute to the FRB overstatement (understatement) of production. Problems such as these give rise to the proposed adjustment, $r(Q/I_{FRB})$.

3.2.2 Physical Measures of Production

For the most energy-intensive industries (Group 2) shown in Table 1, trade associations have provided energy efficiency data that measure production in tons of product. Tons of product is used here as the physical measure of production, Q, for each of these industries except petroleum products, where physical output is measured in barrels (see Table 3).

The less energy-intensive industries (Group 1) identified in Table 1 (i.e., SICs 20 and 22) are so heterogeneous that construction of a physical measure of production for this purpose is difficult. Hence the FRB indexes for Group 1 industries are not adjusted for projection purposes. A refinement for future consideration would be the construction of an energy-weighted index based on the most energy-intensive products in Group 1. However, it should be noted that good physical measures of production are not always available even at the four-digit SIC level for Group 1.

TABLE 3 Physical Measures of Production for Selected Energy-Intensive Industries

Industry	SIC	Measure of Production
Paper and allied products	26	Production of paper and board (tons)
Chemicals and allied products	28	Aggregate weight of 48 products[a]
Petroleum and coal products	29	Crude runs to stills (bbl)
Primary metals (total)	33	Energy-weighted combination
Steel		Steel mill products (tons)
Nonferrous metals		Energy-weighted aluminum production[b]

[a]Ref. 11.

[b]Ref. 12.

3.2.3 Historical Relationship Between Q and I_{FRB}

It is assumed that the growth rate in the ratio Q/I_{FRB} is constant. This condition results from an equivalent difference in growth rates for each index, as specified by regression analysis for the period 1969-79. The computed difference is indicated in Eq. 2 as $r(Q/I_{FRB})$, expressed in percent per year. The results are shown in Table 4. SICs 26, 28, and 33 typify the downstream shift and heterogeneity problems. While primary paper, chemical, and steel production must always be present in the industries, there are many possibilities for growth in high-value-added products that use these basic inputs. The value added grows faster than basic production, hence the negative adjustment. Unlike the adjustments for the paper, chemical, and steel industries, the historical difference between Q and I_{FRB} for the petroleum industry is positive. This is due to a trend toward an increasing share of residual oil production, which has a low value added.

3.3 ESTIMATES OF CHANGES IN ENERGY INTENSITY

Energy intensity, defined as energy use per unit of output, (E/Q), can differ over time because of changes in process technology and material flows within a sector. (The latter effect is exemplified by steel production, where the increasing relative role of scrap steel is causing a declining relative role for the energy-intensive blast furnace.) In the following section, energy intensity is distinguished for two forms of energy: fuel use (i.e., total energy exclusive of purchased electricity) and purchased electricity.

In this section, as well as in the next section (Sec. 3.4) on forecasting, the rate of change in E/Q is dealt with rather than absolute levels of this ratio. Using a rate of

TABLE 4 FRB Production Index Adjustment Required to Obtain the Growth Rate in Physical Production

Industry	SIC	Adjustment (%/yr)
Food and kindred products	20	[a]
Textile mill products	22	[a]
Paper and allied products	26	-0.6[b]
Chemicals and allied products	28	-1.8[b]
Petroleum and coal products	29	+0.7[c]
Primary metals (total)	33	-0.5[c]

[a]No adjustment attempted at this time.

[b]Ref. 12.

[c]Based on regression analysis of the physical product indexes reported in Table 3.

change avoids the problem of differing definitions of output, Q, that may be used by different analysts and modelers. In particular, this makes the connection between the historical analysis in this section and the forecast in the NEPP much simpler. We assume that the rates of change in E/Q will be similar,* even if the absolute level of E/Q is not.

3.3.1 Computation of the Changes in Energy Intensity

The major data source for this analysis is the Annual Survey of Manufactures (ASM) published by the Bureau of the Census.[13] There are, however, other sources for these data that vary in frequency and comprehensiveness. The ASM reports purchased fuels only; thus the importance of nonpurchased fuels must be inferred from other sources. Trade associations are the major source for data on industries with large non-purchased fuel components. Due to accounting procedures and assumed conversion factors, various sources may not be consistent and can give different values for the 'same' energy source. Care has been taken to minimize inconsistencies in the data used here; however, comparison to other sources may be misleading. Use of ASM data naturally yields projections of purchased fuels only.

*For comparison purposes, it is useful to note that the average annual rate of decline in fossil fuel intensity, reported by the NEPP from 1970 to 1980, is slightly less than 4% per annum. This rate would also include any downstream shift that occurred during the period. In addition, this is the rate for all of industry, not just for manufacturing.

Although the ASM reports data down to the four-digit level, only two-digit-level data are used here. The use of two-digit SIC data minimizes one source of inconsistency. For instance, a plant is normally categorized into a four-digit industry by its major product. However, many plants produce products that cut across four-digit industry classifications. As a result, a plant's major product could conceivably be as little as 50% or less of the plant output. This classification procedure leads to problems when considering energy use in an industry; total energy use in a plant would be assigned to its major product industry, and if less than 100% of the plant output fell in that industry group, the energy intensity value (E/Q) would be biased upward. Aggregation to the two-digit level eliminates this source of measurement error.

In most cases, estimates of r(E/Q) for the 20 two-digit manufacturing industries (SICs 20-39) and two energy types, fossil fuel and electricity, were obtained by performing regression analysis on ASM data for purchased energy. However, there are some special scenarios with respect to fossil fuel consumption. Particular industries that use a significant amount of nonpurchased fuel -- SICs 26, 28, 29, and 33 -- were excluded from the regression analysis; estimates of r(E/Q) for fossil fuel use in these industries were obtained from other sources, as described below.

Total energy intensity and rates of conservation have been studied in detail by the paper (SIC 26), chemicals (SIC 28), petroleum (SIC 29), and steel (SIC 33) trade associations for the period since 1972.[14] As a result, these published figures should comprise accurate estimates of r(E/Q) for fossil fuel use in those industries. In addition, use of these estimates circumvents the data problems surrounding purchased vs. non-purchased fuel use, since the ASM only reports purchased fuel use.

For the remaining industries and energy types (both fossil fuel and electricity), estimates of $r(E/I_{FRB})$ are derived from historical trends in ASM data. The historical estimate of $r(Q/I_{FRB})$ from Table 4 is then subtracted from the estimate of $r(E/I_{FRB})$ (see Table A.2) to arrive at an estimate of r(E/Q). This last step only applies to SICs 26, 28, 29, and 33, since adjustments for all other industries were not attempted at this time. For these other industries, $r(E/I_{FRB})$ equals r(E/Q). The resulting growth rates of E/Q for all six industries and two fuel types are presented in Table 5.

Since capacity utilization can have a significant impact on energy intensity, it is desirable to control for this effect when estimating the growth rates, $r(E/I_{FRB})$. Low capacity utilization in recessions tends to raise the energy-output ratio, thus biasing growth rate estimates upward. The estimation methodology and discussion of capacity utilization is found in App. A.

3.3.2 Interpretation of Estimated Changes in Energy Intensity

It is desirable to consider the reasonableness of the sign and magnitude for the estimated growth rates. Since no persuasive measure of growth in physical production exists for the Group 1 industries, it is not possible to fully assess the estimates. However, for fuel use, they are in the same range as those for Group 2, and estimates for electricity show moderate conservation.

TABLE 5 Rate of Energy Intensity Change in the 1970s (Growth Rates of E/Q)[a]

Industry	SIC	Fuel Use Rate (%)	Fuel Use Period	Electricity Rate (%)	Electricity Period
Group 1					
Food and kindred products	20	-3.8	1974-81	-1.9	1969-81
Textile mill products	22	-2.2	1974-81	-1.1	1969-81
Group 2					
Paper and allied products	26	-3.1[b,c]	1972-81	2.13	1969-81
Chemicals and allied products	28	-3.0[b]	1972-81	-0.15	1969-81
Petroleum and coal products	29	-1.0[b]	1972-81	-0.55	1969-81
Primary metals (total)	33	-2.2[d]	1972-81	2.63	1973-81
Steel		-1.8[b]	1972-81	3.06	1973-81
Nonferrous metals		-3.4	1974-81	1.91	1973-81

[a]From ASM data[13] except when specified.

[b]From trade association reports to the Department of Energy for total energy use per unit of production, unadjusted for environmental control and product mix changes.

[c]Purchased energy only.

[d]Rates constructed as a weighted sum of the two subsectors with weights from energy use in 1980. The weights are 0.78 and 0.22 for steel and nonferrous metals, respectively.

Electricity use per unit of output shows a mixed pattern: food, textiles, and petroleum refining show mild declines, and paper and metals show significant increases. There is virtually no change in the chemical industry. Most of these results may make sense in that pumps and other motor drive services are being used more efficiently. Electric melting is playing an increasingly important role in metals manufacture. Increased use of electric arc furnaces in the steel industry should be responsible for roughly a 1%/yr growth rate, explaining much of the result shown for steel. However, the efficiency improvements in the nonferrous metals sector, particularly aluminum smelting, which is a dominant electricity user, are not revealed in this result. Trends in electrification for copper smelting and aluminum scrap reduction presumably outweigh these efficiency gains. In the paper industry, some steam power is being switched to electricity and an electrically intensive pulping process called thermomechanical pulping, which was widely implemented in the late 1970s, so that the result for this sector is also reasonable.

Although most of the results presented in Table 5 appear reasonable, some cross-checking could be performed. For example, electricity use reported in the ASM could be compared with trade association data. Detailed investigation of electrical melting and other increased uses of electric technologies would provide a check on industry-to-industry differences in electricity intensity. Finally, as mentioned above, a more appropriate index of production for industries in Group 1 would be desirable. (Department of Labor output indexes may provide some of the desirable improvements.)

3.4 FORECAST OF ENERGY INTENSITY CHANGES

The forecast for energy intensity changes is based on three ingredients: (1) the recent trends discussed in Sec. 3.3; (2) the remaining extensive, albeit eventually limited, opportunities for continued change in the directions established in the 1970s (both for efficiency improvement and electrification); and (3) the strong likelihood that continued change will be governed by capital expenditure limitations.

It has been established by Ross[14] that great opportunities for cost-effective improvements in energy use still exist in energy-intensive industries. The reason is that only a small fraction of known conservation opportunities requiring substantial investment have been undertaken by most firms. In addition, the pace of investment in most firms is slow, reflecting the fact that hurdle rates for conservation projects are far higher than the cost of capital.[15] (The progress apparent for fuels identified in Table 5 is largely due to operational improvements.) Moreover, in almost all firms, projects that are profitable but require a relatively high level of engineering effort by the firm, such as advanced computer control and distillation projects, are being approached slowly.

From a technical perspective, the energy-efficiency improvement possibilities run the gamut from insulation and heat recovery to advanced computer controls and process changes. Opportunities to reduce electrical costs include demand controls, more-efficient motors, electric motor controls where loads vary, relamping, and, again, process change. The range of opportunities is, in fact, greater than the range of methods of manufacture, since for each manufacturing process there are several types of efficiency improvements. In addition, there are a number of opportunities for substituting electricity for fuel, the most important of which involve specific heating: heating of products specifically rather than the space that contains the product. This potential for both decreases and increases in efficiency improvements makes analysis and forecasting of electricity use per unit of production particularly difficult.

In a study by Ross on industrial energy conservation,[14] a detailed analysis of fuel use in the steel and paper sectors shows that the rate of fuel efficiency improvement in the 1980s and perhaps 1990s is likely to be similar to that of the 1970s. The argument rests on data reflecting the capital cost of energy-efficiency improvements and the assumption that the rate of capital spending on such improvements established for 1980-81 would continue as long as profitable opportunities remained. This model is one of inertia in capital spending; the shock of 1979 mobilized large energy-intensive firms into organizational and capital spending changes that may well remain in effect. As mentioned, highly profitable opportunities are available; their profitability has not been strongly influenced by the recent pause in fuel price escalation.

The argument for extrapolating the rates of improvement r(E/Q) achieved in the 1970s (see values in Table 5) is based on a number of factors. Some of these factors were identified in the previous paragraphs. Another factor is the transparent nature of the approach. Such an approach is useful as an alternative to complex models, which have other less-obvious flaws. It is not, however, realistic to extend such rates to 2030 with this method. In order to control the total change, the period of time is broken into three periods: 1980 to 1995, 1996 to 2010, and 2011 to 2030. It is assumed that the rates of change (presented in Table 5) decline linearly to one half of their value by the end of the first period, then decline to zero by the end of the second period. In the third period (2011-2030), zero growth is assumed. Tables 6 and 7 present the rates of changes for fossil fuels and electricity, respectively, by sector and time period. The overall changes -- growth and decline -- over the 50-yr period are reasonable results for the technologies involved according to present conceptions.

The second component of the forecast methodology developed here is the forecast of $r(Q/I_{FRB})$ presented in Table 4. Unlike the forecast for the rate of change in energy intensity discussed above, which is expected to go to zero, convincing arguments can be given for at least three of the four industry output adjustments to continue indefinitely. In the chemicals, paper, and steel industries, a strong shift to downstream processing is implied by the negative adjustment factors. This shift can continue as long as new, highly processed products are developed. This assumption is easy to justify for the chemical industry, where new chemicals and pharmaceuticals are being continually developed. To a lesser extent, the same can be said for paper and steel, where new uses for paperboard, containers, and particularly coated papers are appearing, and as the

TABLE 6 Examples of Changes in Fuel Intensity (growth rates of E/Q)

Industry	SIC	Change in Intensity (%/yr)		
		1980	1995	2010[a]
Food and kindred products	20	-3.8	-1.9	0
Textile mill products	22	-2.2	-1.1	0
Paper and allied products[b]	26	-3.0	-1.5	0
Chemicals and allied products	28	-3.0	-1.5	0
Petroleum and coal products	29	-1.0	-0.5	0
Primary metals (total)	33	-2.2	-1.1	0

[a]There is no change in intensity from 2010 until 2030.

[b]Excludes contribution of biomass fuels. If biomass fuels are included, use intensity changes of -1, -0.5, and 0%/yr, respectively.

TABLE 7 Examples of Changes in Purchased Electricity Intensity (growth rates of E/Q)

Industry	SIC	Change in Intensity (%/yr) 1980	1995	2010[a]
Food and kindred products	20	-1.9	-0.95	0
Textile mill products	22	-1.1	-0.55	0
Paper and allied products	26	2.1	1.1	0
Chemicals and allied products	28	-0.15	-0.07	0
Petroleum and coal products	29	-0.5	-0.3	0
Primary metals (total)	33	2.6	1.3	0

[a]There is no change in intensity from 2010 until 2030.

emphasis in the steel industry shifts to fabricated products. However, as noted above, it may not be realistic to extend these rates to 2030. Therefore, the forecasts for $r(Q/I_{FRB})$ in the period 2010-2030 will be lower than the 1980-2009 forecasts recommended in Table 4. The forecasts in the period 2010-2030 of $r(Q/I_{FRB})$ for the paper, chemicals, and steel industries are assumed to be -0.4%, -1.4%, and -0.3%, respectively.

The shift in the petroleum industry, however, requires more microscopic evaluation. The positive adjustment factor $r(Q/I_{FRB})$ for petroleum refining (see Table 4) implies a shift toward less-refined, low-value-added products. By examination of the value-added weights used by the FRB index for a few major products, the cause of the difference in the physical output and FRB production trends can be discerned. The value-added weights for gasoline, distillate oil, and aviation fuel are, respectively, 17, 6, and 3 times the weight assigned to residual fuel oil. During the period 1972-79, the average annual rates of growth of physical output for gasoline, distillate oil, aviation fuel, and residual fuel were, respectively, 1.1%, 2.2%, 2.1%, and 9.3%.[16] Sluggish growth in gasoline output and increased residual production appears to be the cause of the difference in the two measures of output.

For forecasting purposes, however, this trend is not expected to continue. Recently, several large oil refiners have completed capital conversions to process residual oil into higher-value-added products.[17] High prices for residual oil in 1983 and 1984 suggest that lower demand will prevail.[18] Thus, $r(Q/I_{FRB})$ for SIC 29 is set to zero for forecast purposes. This is not as extreme a measure as it appears. It says that the trend toward residual oil production will cease, but it does not forecast a reverse in the trend.

For the energy efficiency adjustment in the refinery sector, the forecast of r(E/Q) is retained. However, a future shift toward more-refined products and away from residual oil may tend to increase E/Q and result in a slower improvement in energy use per barrel of refinery output. Hence, the future of the refinery sector presents some uncertainties that may be partially resolved through a more detailed study of future expectations for that industry. It should be pointed out that it is not sufficient to observe the mix of domestic oil consumption as an indicator of the refinery output slate. Imports of refined products make up a substantial and growing portion of oil imports. The size and composition of these imports significantly affect the domestic oil-refining industry.

3.5 SUMMARY OF PROPOSED PROCEDURE

In this section, the components of a procedure to forecast fuel and electricity use in several manufacturing sectors are presented. The procedure is defined in Eq. 2. One component of the procedure is the index of industrial production, I_{FRB}. A forecast growth rate for I_{FRB} in any year is affected by two terms: (1) an adjustment to obtain a physical measure of production Q, reported in Table 4, and (2) a rate of change in energy intensity, by fuel type, provided in Tables 6 and 8. All values are expressed in annual percentage changes. For example, if the FRB index for chemicals is forecast to grow 3.0% in the year 1995, the forecast change in fossil fuel use in that year is:

$$r(E) = 3.0 - 1.8 - 1.5 = -0.3\%$$

where -1.8 and -1.5 are taken from Tables 4 and 6, respectively. Combining growth rates calculated in this fashion with base-year data yields estimates of future industrial fossil fuel use.

As a final note it should be pointed out that the industry energy growth rates obtained in this fashion are relative. The national average rate of energy growth (or decline) is obtained from the NEPP-85. A large growth rate for one industry compared to the other industries may simply mean that energy use for that industry declines more slowly, if the national average rate is negative.

4 BOILER FUEL USE BY INDUSTRY GROUP: METHODOLOGY

The methodology employed to generate national control totals for boiler fossil fuel use by industry group is presented in this section. The driver data requirements are defined first, then the general methodology and detailed procedures employed to generate the driver data are described.

4.1 DRIVER DATA REQUIREMENTS

Industry-specific projections of fossil fuel consumption by boilers at the state level are required as inputs to the ICE model. Specifically, the ICE model requires boiler fuel projections for seven industry groups: food, textiles, paper and allied products, chemicals and allied products, petroleum and coal products, primary metals, and all other (other manufacturing, agriculture, construction, and mining). This section describes the methods for developing the industry-specific projections of boiler fuel use at the national level. The state-level projections for ICE are based on these national projections.

As indicated, all projections for Phase 1 activities were required to be derived from official DOE projections of industrial energy demand as reported in NEPP-85. However, projections of industry-specific boiler fuel demand are not included in the NEPP projections; NEPP projections include total industrial fossil-fuel consumption excluding nonenergy feedstocks. (This projection does include industrial consumption of metallurgical coal, however.) The remainder of this section describes the procedures for (1) dividing total industrial fossil-fuel projections in the NEPP among specific industry groups and (2) estimating the boiler fuel requirements of each industry group.

4.2 OVERVIEW OF BOILER FUEL PROJECTION METHODOLOGY

The boiler fuel projection methodology consists of four steps summarized below:

1. Base-year data for the projections are compiled. The boiler fuel projections are based on industry-specific data on consumption of purchased fossil fuel published in the 1980 ASM.[13] The year 1980 is used because it was chosen as the base year for Phase 1 activities. It should be noted that 1980 is a fairly representative year: it was a recession year, although not a severe one, and industrial fuel consumption in 1980 appears to be in line with other comparable years.

2. Industry-specific growth rates are applied to the base-year fuel data to obtain industry-specific projections of fossil fuel use. At this point, the fuel consumption projections are unadjusted, so the industrial totals may not match the NEPP projections.

3. The fossil fuel projections are then adjusted so that total industrial fossil-fuel consumption summed across all industries matches the NEPP projections.

4. Boiler fuel ratios (fraction of fossil fuel consumed as boiler fuel for each industry) are then applied to the adjusted projections to derive the industry-specific projections of boiler fuel use.

The following sections describe the projection methods and data sources in more detail.

4.3 FOSSIL FUEL EQUATION

The six major industry groups at the two-digit SIC level required by the ICE model account for the bulk (74.5% in 1980) of fuel consumed by all manufacturing industries (9.23 quads).* The six energy-intensive industries are: food (SIC 20), textiles (SIC 22), paper and allied products (SIC 26), chemicals and allied products (SIC 28), petroleum and coal products (SIC 29), and primary metals (SIC 33). Because energy use patterns in recent years have been changing in these industries, a detailed method for projecting fuel consumption growth rates in these industries is adopted. This method is described in Sec. 4.4. Other manufacturing industries, that is, the 14 industries with SICs 20 to 39 other than the six of concern here (20, 22, 26, 28, 29, and 33), account for the remaining 25.5% of fuel consumed in manufacturing. The same approach is used to project energy demand for each of these industries.

For completeness, the three energy-intensive sectors classified as nonmanufacturing industries are also included in this analysis. The agriculture, mining, and construction sectors have been estimated to consume 2.2 quads per year of fossil fuel.[19] However, due to the paucity of historical data on fuel consumption in agriculture, construction, and mining, a simple approach is adopted for projecting fuel consumption by these sectors. This approach is described in Sec. 4.5.

4.4 MANUFACTURING INDUSTRIES

The following equation is used to estimate demand for purchased fossil fuels used for heat and power by each of the manufacturing industries (SICs 20 to 39):

$$FEC_i(t) = [F_i(1980) - C_i(1980)] \prod_{u=1980}^{t} [1 + R_i(u)] \qquad (4)$$

$$\text{for } i = 1, \ldots, 20$$

---

*The stone, clay, and glass industry (SIC 32) also accounted for a sizable (10.5%) portion of the purchased fuel consumed by manufacturing in 1980. This industry's fuel demand is grouped into the "other" manufacturing category with respect to the ICE model inputs, since SIC 32 uses very little boiler fuel.

where

$FEC_i(t)$ = unadjusted projection of purchased fossil fuel use (excluding coke), by industry i in year t (t > 1980),

$F_i(1980)$ = total purchased fossil fuel use (including coke), by industry i in 1980,

$C_i(1980)$ = purchased coke, by industry i in 1980, and

$R_i(u)$ = growth rate of fuel consumption, by industry i in year u.

Purchased fossil fuels used in manufacturing [$F_i(1980)$] and coke consumption [$C_i(1980)$] for 1980 are taken from the ASM.[13] This adjustment was insignificant for most of the six industries considered in the ICE model. The primary metals industry (SIC 33, which includes iron and steel production) was the only industry consuming a significant amount of purchased coke (0.39 quads in 1980).

The fuel consumption growth rates by industry, $R_i(t)$ in Eq. 4, are derived through the procedure described in Sec. 3. In that section, DRI's projected FRB indexes of industrial production are adjusted to account for recent observed trends affecting energy use and output in each industry. These adjustments reflect (1) the observed relationship between growth in the FRB index and an index of physical output and (2) the observed relationship between growth in fuel consumed and an index of physical output. This procedure is followed because the adjusted indexes for some industries represent a more accurate measure of industry-specific growth in energy use than the FRB indexes.

Projections of the FRB indexes are obtained directly from DRI output for two of the three scenarios examined in the 1985 test runs: DOE reference scenario and the low scenario (equivalent to the DRI pessimistic forecast for Fall 1984). Each of these forecasts covered the period 1984-2009. To comply with the time horizon specified for Phase 1 test runs, DRI was commissioned to extend its macroeconomic forecasts to the year 2030.[6] As a separate activity, Argonne developed a projection of FRB indexes commensurate with the high economic growth scenario contained in the NEPP-85. DRI did not generate such a forecast. The methodology and results of this activity are documented in App. B.

A listing of the projected FRB indexes for each scenario is contained in App. B for the time period 1980-2030. Table 8 presents projected FRB indexes for the DOE reference scenario between the years 1980 and 2005. The adjustment factors generated in Sec. 3 for each industry group are reported in Table 9 for two time periods, 1985 and 2000.

TABLE 8 Projected FRB Indexes: DOE Reference Scenario

Industry	SIC	FRB Index, by Year					
		1980	1985	1990	1995	2000	2005
Food and kindred products	20	1.50	1.69	1.92	2.16	2.36	2.59
Textile mill products	22	1.39	1.50	1.87	1.97	2.18	2.43
Paper and allied products	26	1.51	1.80	2.11	2.40	2.65	2.95
Chemicals and allied products	28	2.07	2.47	3.31	4.14	5.00	6.07
Petroleum and coal products	29	1.33	1.32	1.50	1.57	1.64	1.71
Primary metals	33	1.02	1.10	1.42	1.55	1.74	1.96

TABLE 9 Examples of Adjustment Factors for FRB Growth Rates

Industry	SIC	Annual % Change, by Year	
		1985	2000
Food and kindred products	20	-3.8	-1.5
Textile mill products	22	-2.2	-0.9
Paper and allied products	26	-3.7	-1.3
Chemicals and allied products	28	-4.8	-3.0
Petroleum and coal products	29	-1.0	-0.4
Primary metals	33	-2.7	-1.1

4.5 NONMANUFACTURING INDUSTRIES

The following equation is used to project demand for purchased fossil fuels in nonmanufacturing industries -- agriculture, mining, and construction. It is assumed that these sectors maintain a constant share of total industrial energy use based on 1980 estimates of fuel consumption. In the remainder of the report, agriculture, mining, and construction are referred to as the AMC sectors.

$$FEC_{21}(t) = FEC_{21}(1980) \frac{\sum_{i=1}^{20} FEC_i(t)}{\sum_{i=1}^{20} FEC_i(1980)} \qquad (5)$$

where

$FEC_{21}(t)$ = projection of fossil fuels consumed by the AMC sectors in year t,

$FEC_{21}(1980)$ = estimated fossil fuels consumed by the AMC sectors in 1980,

$FEC_i(t)$ = projection of fossil fuels consumed by manufacturing sector i (i = 1, 2, ..., 20) in year t, and

$FEC_i(1980)$ = fossil fuels consumed by manufacturing sector i (i = 1, 2, ..., 20) in 1980.

Base-year fossil fuel consumption in the AMC sectors, $FEC_{21}(1980)$ in Eq. 5, was estimated to be approximately 2.2 quads. This estimate was derived from various types of data reported by the Energy Information Administration (EIA) over a series of years during the 1977-1981 time period.[19] The EIA figures represent total fossil fuel use; no distinction is made between purchased and nonpurchased fuel. For lack of information to derive better estimates, it is assumed that all 2.2 quads of fossil fuel consumed by the AMC sectors are purchased fuel.

At the time these projections were made, growth rates specific to the AMC industries were not available, necessitating the assumption of a constant share. An area for future improvement would be the inclusion of sector-specific growth rates for the AMC sectors.

4.6 FACTOR FOR SCALING TO NEPP PROJECTIONS

The fossil fuel projections are adjusted to be consistent with the NEPP-85 industrial totals. The scaling factor is computed from the following equation.

$$N(t) = [NEPP(t) - 1.05] \; / \; [FEC_i(t) + NP_j(t)] \tag{6}$$

where

$NEPP(t)$ = NEPP-85 projection of industrial fossil fuel demand (sum of liquids, gases, and coal solids), excluding nonenergy feedstocks, for year t,

1.05 = industrial consumption of coke in 1980,*

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*The estimate of coke consumption is held constant throughout the projection period. Due to sluggish growth in SIC 33 and recent trends toward scrap reduction, the assumption of no growth in coke use was felt to be reasonable.

$NP_j(t)$ = projected nonpurchased fossil fuels (excluding biomass) used by industry j at time t, and

$FEC_i(t)$ = projection of fossil fuels consumed by manufacturing sector i (i = 1, 2, ... 21) in year t.

A few comments on Eq. 6 are in order. The quantity 1.05, coke consumption, is subtracted from the NEPP projection in the numerator of Eq. 6 for consistency -- the quantities in the denominator of the equation do not include coke. An estimate of nonpurchased fossil fuel consumption is included in the denominator of Eq. 6 because the NEPP total in the numerator, NEPP(t), includes nonpurchased as well as purchased fossil fuels.

Estimates of nonpurchased fuel consumption by industry are reported by the EIA (see Table 10). Nonpurchased fuel consumption for SIC 26 (paper) and SIC 24 (lumber and wood), although sizable, consists largely of biomass residues rather than fossil fuels. Under the assumption that nonpurchased fuel consumption for the chemicals, petroleum, and primary metals industries consists largely of fossil fuel, estimates of nonpurchased fossil fuel are significant only for these three industries. Nonpurchased fossil fuel projections, $NP_j(t)$ for j = 1, 2, 3 in Eq. 6, are based on the 1980 base-year values for these three industries reported in Table 10. The growth rates applied to nonpurchased fossil fuel use are the same ones used in Eq. 4.

The estimate of coke consumption, 1.05, is derived from estimates of metallurgical coal consumption[21] and allows for conversion to coke and by-product gases. This procedure is followed for accounting reasons. A separate projection category is required for nonpurchased fuel in SIC 33, primary metals. Metallurgical coal is the sum of coke and by-products. By-product gases are accounted for as nonpurchased fuels, so the estimate of nonpurchased fuel from Table 10 for SIC 33 is subtracted from the estimate

TABLE 10 Nonpurchased Fuel Consumption Estimates, by Industry

Industry	SIC	1980 Fuel Consumption (10^{12} Btu)
Lumber and wood	24	95.4
Paper and allied products	26	1145.8
Chemicals and allied products	28	408.4
Petroleum and coal products	29	2448.6
Primary metal	33	739.0
All other manufacturing		69.1

Source: Ref. 20.

of metallurgical coal consumption, 1.79 quads, to arrive at the coke consumption estimate. Subtracting metallurgical coal from the NEPP total would count the non-purchased fuels in SIC 33 twice.

The fossil fuel projection in each year t, $FEC_i(t)$ for i = 1, 2, ..., 21, is multiplied by the adjustment factor N(t), from Eq. 6, for year t to obtain adjusted fossil fuel totals that are consistent with the NEPP-85 totals. The scaled projections are computed from the following equation.

$$FEC_i'(t) = FEC_i(t)\ N(t) \text{ for } i = 1, 2, \ldots, 21 \tag{7}$$

where

$FEC_i(t)$ = unadjusted projection of purchased fossil fuel use (from Eqs. 4 and 5),

$N(t)$ = NEPP-85 adjustment factor (from Eq. 6), and

$FEC_i'(t)$ = adjusted projection of purchased fossil fuel use.

The sum of $FEC_i'(t)$ for i = 1, 2, ..., 21 equals the NEPP-85 projection for industrial fossil fuels (excluding nonenergy feedstocks) less coke consumption and less adjusted non-purchased fossil fuels. The adjusted projections of purchased fossil fuel, $FEC_i'(t)$, are the ones upon which the boiler fuel projections are based.

The next section describes the procedure for obtaining the boiler projections from the adjusted fossil fuel projections [$FEC_i'(t)$].

4.7 BOILER FUEL EQUATION

Projections of purchased fossil fuels for use in boilers are based on the following equation:

$$B_i(t) = FEC_i'(t)\ BF_i \text{ for } i = 1, 2, \ldots, 21 \tag{8}$$

where

BF_i = estimated fraction of purchased fossil fuel used in boilers in industry i.*

*BF_i may be thought of as a transformation rather than a fraction, particularly for the petroleum industry. The ICE model base-year data include refinery use of residual fuel oil, which is not purchased, and therefore not in the ASM. This ratio, BF_i, therefore accounts for refinery use of residual fuel oil.

$FEC_i'(t)$ is from Eq. 7. The boiler fuel fractions, BF_i in Eq. 8, were calculated as follows. For SICs 20, 22, 26, 28, 29, and 33, BF_i was calculated as:

$$BF_i = ICE_i / ASM_i$$

where

ICE_i = total purchased fossil fuel used by boilers in SIC group i, in Btu, taken from the ICE model data base for 1980, and

ASM_i = total purchased fossil fuel (excluding coke and breeze) used for heat and power in SIC group i, in Btu, taken from the 1980 ASM.[13]

For the "other" category, which includes other manufacturing (i.e., SICs 20 to 39 excluding 20, 22, 26, 28, 29, and 33) and agriculture, construction, and mining, BF_o was calculated as:

$$BF_o = ICE_o / (ASM_o + AMC)$$

where

ICE_o = total purchased fossil fuel used by boilers for these industries, in Btu, taken from the ICE model data base for 1980,

ASM_o = total purchased fossil fuel (excluding coke and breeze) used for heat and power in manufacturing industries, excluding SIC groups 20, 22, 26, 28, 29, and 33, in Btu, taken from the 1980 ASM, and

AMC = total estimated fossil fuel consumed by the agriculture, mining, and construction industries, in Btu.

Boiler fuel fractions are shown in Table 11.

TABLE 11 National Boiler Fuel Fractions

Industry	SIC	Boiler Fuel Fraction[a]
Food and kindred products	20	0.5630
Textile mill products	22	0.6777
Paper and allied products	26	0.6849
Chemicals and allied products	28	0.5008
Petroleum and coal products	29	0.3453
Primary metals	33	0.3458
Other manufacturing		0.3312

[a]Excluding fossil fuels used as nonenergy feedstocks.

5 PURCHASED FOSSIL FUEL USE IN BOILERS: PROJECTIONS BY INDUSTRY

This section presents the results of the procedures for projecting purchased boiler fuel use. Tables 12-14 list the reference, low, and high scenario projections, based on Eq. 8, of purchased fossil fuel use for boilers by industry group. The state-level projections that will be the direct inputs to the ICE model are based on these national industry totals.

Figures 7-9 illustrate the projections by industry for each scenario. Plotted points for the period 1980-1983 reflect the application of estimated energy-intensity correction factors to historical values of FRB indexes. Plots for these years are also scaled to NEPP control totals. For these reasons, the plotted data for 1980-1983 should not be regarded as the historical levels of energy consumption during those years.

Not unexpectedly, the projections for several specific industries exhibit basically the same time pattern as NEPP-85 fossil fuel projections (see Fig. 6). Fuel consumption increases in the near-term and then levels off in the reference scenario. However, some shifting of industrial sector shares is indicated by the projections. In spite of a large correction factor for the chemical industry growth rate (see Table 9), that industry's boiler fuel use continues to grow in the reference and high scenarios. From Figs. 7-9, it appears that three industries are more sensitive to differences in GNP across scenarios (i.e., they have larger income elasticities): chemicals, paper, and primary metals. The other three industries (food, textiles, and refining) appear less sensitive to the GNP scenario changes.

TABLE 12 Projected Demand for Purchased Boiler Fuel: Reference Scenario[a]

		Purchased Boiler Fuel, by Year (10^{12} Btu/yr)[a]								
Industry	SIC	1980	1985	1990	1995	2000	2005	2010	2020	2030
Food and kindred products	20	455	410	463	458	435	437	433	461	486
Textile mill products	22	140	130	170	165	164	170	166	167	164
Paper and allied products	26	760	721	838	831	785	981	763	777	777
Chemicals and allied products	28	1132	1018	1279	1316	1279	1311	1321	1435	1528
Petroleum and coal products	29	369	330	413	413	394	388	372	348	321
Primary metals	33	460	414	549	538	526	537	526	484	427
Other industry		1538	1376	1693	1657	1602	1645	1649	1707	1725
Total		4854	4399	5405	5383	5185	5259	5230	5379	5428

[a]Numbers represent purchased steam coal, natural gas, and petroleum products for combustion in boilers.

TABLE 13 Projected Demand for Purchased Boiler Fuel: Low Scenario

Industry	SIC	Purchased Boiler Fuel, by Year (10^{12} Btu/yr)[a]								
		1980	1985	1990	1995	2000	2005	2010	2020	2030
Food and kindred products	20	455	405	452	434	400	391	388	402	401
Textile mill products	22	140	128	150	139	131	129	124	119	110
Paper and allied products	26	760	712	803	770	711	690	678	684	662
Chemicals and allied products	28	1132	1003	1168	1158	1085	1066	1066	1128	1144
Petroleum and coal products	29	369	325	396	385	359	344	326	305	274
Primary metals	33	460	396	453	424	392	382	362	330	287
Other industry		1538	1341	1512	1431	1342	1335	1333	1387	1388
Total		4854	4310	4934	4741	4420	4337	4277	4355	4266

[a]Numbers represent purchased steam coal, natural gas, and petroleum products for combustion in boilers.

TABLE 14 Projected Demand for Purchased Boiler Fuel: High Scenario

Industry	SIC	Purchased Boiler Fuel, by Year (10^{12} Btu/yr)[a]								
		1980	1985	1990	1995	2000	2005	2010	2020	2030
Food and kindred products	20	455	404	460	471	463	486	509	583	676
Textile mill products	22	140	130	171	177	181	195	203	219	235
Paper and allied products	26	760	711	842	862	842	872	899	974	1062
Chemicals and allied products	28	1132	1003	1305	1401	1435	1559	1688	2029	2376
Petroleum and coal products	29	369	329	410	424	415	423	422	412	411
Primary metals	33	460	427	567	583	510	625	652	623	590
Other industry		1558	1380	1721	1759	1762	1885	2007	2196	2401
Total		4854	4384	5476	5677	5688	6045	6380	7036	7751

[a]Numbers represent purchased steam coal, natural gas, and petroleum products for combustion in boilers.

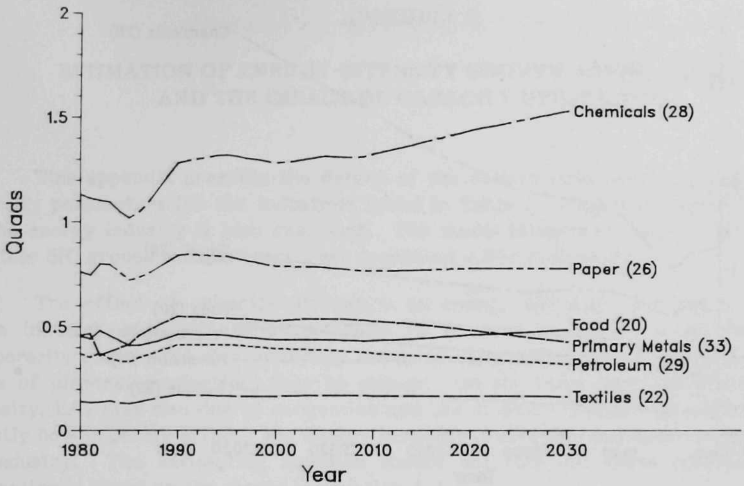

FIGURE 7 Projected Demand for Purchased Boiler Fuel by Industry Group: Reference Scenario

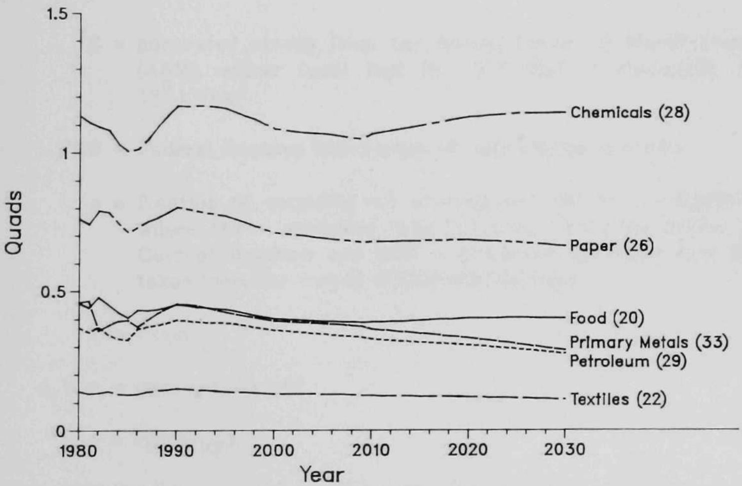

FIGURE 8 Projected Demand for Purchased Boiler Fuel by Industry Group: Low Scenario

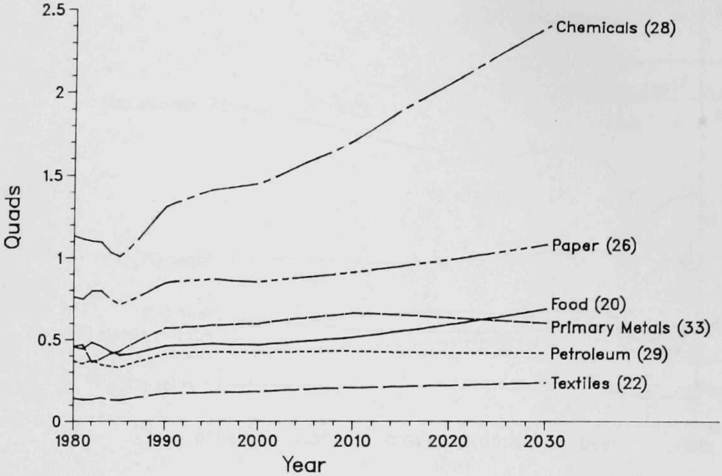

FIGURE 9 Projected Demand for Purchased Boiler Fuel by Industry Group: High Scenario

APPENDIX A

ESTIMATION OF ENERGY-INTENSITY GROWTH RATES, $r(E/I_{FRB})$, AND THE IMPACT OF CAPACITY UTILIZATION

This appendix presents the details of the econometric estimation of the energy-intensity parameters for the industries listed in Table 1. Impact of capacity utilization on the energy industry is also examined. The model introduced below is also applied to all other SIC groups and the results are presented without discussion.

The effect of capacity utilization on energy intensity need not be monotonic. When industry capacity utilization falls to a level at which entire facilities are temporarily closed, the rise in energy intensity (E/Q, where E = energy use and Q = an index of physical production) may be slower. On the other hand, as utilization nears capacity, E/Q may rise due to congestion and use of older, less-energy-efficient capital. Exactly how capacity affects the energy intensity is an empirical question that may vary by industry. The estimating equation should not rule out these possibilities. The estimation is based on the model in equation A.1.

$$E/FRB_t = e^{(au^2 + bu + c)}\, e^{rt} \tag{A.1}$$

where

E = purchased energy from the Annual Survey of Manufactures (ASM), either fossil fuel (in 10^{12} Btu) or electricity (in 10^9 kWh);*

FRB = Federal Reserve Board index of industrial production;

u = fraction of capacity not utilized, defined by 1 - OR/POR where OR = operating rate (%) taken from the Survey of Current Business and POR = preferred operating rate (%) taken from the Survey of Current Business;

t = time;

a, b, c = parameters; and

r = $r(E/I_{FRB})$.

The year 1969 is taken as the earliest date for the time series because the 1960s represented a different period in energy use and material flows. The time periods for available data used in the analysis are indicated in Table A.1. For comparison, a log

*Except for electricity use in SIC 28, where electricity use from gaseous diffusion plants (in SIC 2819) is subtracted from purchased electricity as reported in the ASM. Uranium enrichment does not usually follow economic trends.

TABLE A.1 Time Periods Used for Regression Analysis of Growth Rates in E/FRB

Industry	SIC	Fuel	Electricity
Food and kindred products	20	1974-81	1969-81
Textile mill products	22	1974-81	1969-81
Paper and allied products	26	N.A.[a]	1969-81
Chemicals and allied products	28	N.A.	1969-81
Petroleum and coal products	29	N.A.	1969-81
Primary metals	33	N.A.	1973-81
Other industry		1974-81	1969-81

[a]N.A. = not applicable (estimates came from other sources instead of our regression analysis for these scenarios).

linear form of Eq. A.1 was estimated as specified, with the restriction a = b = 0, and with a = 0. These will be referred to as the quadratic, the simple, and the linear specifications, respectively. One should note that the quadratic (linear) model is not a quadratic (linear) relationship between u and E/I_{FRB}, but a semilog quadratic (linear) relationship. However, this formulation still allows for congestion when $a > 0$ and $b < 0$, as well as increasing energy intensity at low levels of capacity when $b > 0$ and a is small relative to b. In the linear model, b has the interpretation of a semielasticity; that is, if u changes by one percentage point then energy intensity changes b percent.

For Group 2 industries (i.e., those which are the most energy intensive), the linear specification was best, although the difference between the linear and quadratic models for electricity use in the paper industry was very small. The quadratic specification was the best for the two industries in Group 1. The selection criteria is the adjusted R^2 given by

$$\bar{R}^2 = 1 - (1 - R^2)\,\frac{(n - 1)}{(n - k)} \tag{A.2}$$

where n = number of observations and k = number of parameters, excluding the intercept.

The estimation results for the selected models are given in Table A.2. The growth rate estimates, r, were consistently (but only slightly) lower than those obtained by the simple specification. In Group 2 industries, decreasing capacity utilization raises E/I_{FRB}. This is also true of electricity use in SIC 20. However, the effect slows as utilization gets very low, as in the 1975 recession. The results for textiles and for fuel use in food are similar, in as much as they show a rise in E/I_{FRB} when utilization is very low. However, the results also show a rise in E/I_{FRB} when utilization approaches full capacity. This finding suggests that unit energy use is not minimized at full capacity but rather at levels around 83-87% (see Table A.3) for these industries.

TABLE A.2 Regression Model Results (t-ratios in parenthesis)

Energy Type, Group, and SIC	r	a	b	c	R^2
Purchased Fuel, Group 1					
20	-0.0378	151.7	-42.34	9.66	0.98
	(-17.8)	(2.7)	(-2.7)	(9.0)	
22	-0.022	32.77	-10.98	6.20	0.88
	(-4.8)	(11.2)	(-3.1)	(24.1)	
Purchased Electricity Group 1					
20	-0.019	-136.0	38.7	7.77	0.73
	(-5.5)	(-3.4)	(3.7)	11.3)	
22	-0.011	8.94	-2.3	10.18	0.56
	(-3.8)	(1.5)	(1.4)	(89.5)	
Group 2					
26	0.0153	0	1.125	10.12	0.93
	(10.1)		(6.7)	(511)	
28	-0.0195	0	0.380	11.13	0.78
			(-6.4)	(300)	
29	0.00149	0	1.095	9.88	0.94
	(0.5)		(6.9)	(859)	
33	0.0214	0	0.554	11.58	0.86
	(4.6)		(2.8)	(283)	
Total					
Steel and Iron	0.0267	0	0.284	-10.82	0.95
	(9.7)		(2.4)	(450)	
Nonferrous	0.0142	0	0.786	10.63	0.56
	(1.6)		(2.1)	(137)	

The different results for capacity utilization between industry groups are not surprising. The energy-intensive industries in Group 2 are designed to operate at full capacity. Blast furnaces and large electric motors are left on if they are used at all. Any decrease in utilization that reduces output levels tends to cause a rise in energy intensity. Hence, the linear model fit Group 2 best. In Group 1, a more heterogeneous capital leads to mixed results. From the point of view of unit energy use, congestion is more likely in these industries. Hence, the quadratic model is better for them.

The model and selection criteria presented above were applied to all other SICs for both fuel and electricity. The results are given in Table A.4.

As noted in Table 4, the FRB production index for SIC 33 was adjusted to obtain a growth rate of physical production. The adjustment was derived from the regression model in Eq. A.1. In this scenario, the log of the ratio of the FRB index to an energy-weighted physical product index was regressed against time and fraction of capacity not utilized.[12] This method corresponds to the linear form of Eq. A.1. The results are presented in Table A.5.

TABLE A.3 Critical Points for the Capacity Utilization Curve

SIC	Energy Type	Critical Point	Capacity Utilization[a]
20	Fuel	0.1423	0.8577
22	Fuel	0.1675	0.8325
22	Electricity	0.1286	0.8714

[a]Ratio of actual operating rate to desired rate.

TABLE A.4 Regression Model Results for Other Industries

Fuel Type and SIC	r	a	b	c	R^2
Purchased Fuel					
21[a]	–	–	–	–	-0.2
23[a]	–	–	–	–	-0.3
24	-0.07[b]	0	0.53	146[c]	0.88
25	-0.05[b]	0	-0.88	106[b]	0.82
27	-0.03[b]	0	-0.08	67[b]	0.75
30	-0.10[b]	0	0.29	192[b]	0.96
31	-0.02[c]	40[c]	-13.0[c]	39[b]	0.79
32	-0.05[b]	0	0.29[c]	7[b]	0.99
34	-0.05[b]	0	0.45[c]	101[b]	0.97
35	-0.06[b]	0	-0.43	123[b]	0.98
36	-0.07[b]	79[c]	-2.4[c]	140[b]	0.91
37	-0.04[b]	0	0.53	94[b]	0.94
38	-0.02[b]	20[d]	-6.0[d]	51[b]	0.85
39	-0.03[b]	0	-0.36	70[b]	0.74
Purchased Electricity					
21	0.03[b]	0	-0.7	-51[b]	0.81
23	-0.03[b]	63[c]	-17.0[c]	73[b]	0.82
24	-0.002	0	1.0[c]	12[b]	0.29
25	-0.02[c]	57[d]	-16.0[d]	49[b]	0.48
27	-0.02[c]	85[c]	-25.0[c]	57[b]	0.59
30	-0.04[b]	11[d]	-2.5[d]	82[b]	0.86
31[a]	–	–	–	–	0.03
32	-0.02[b]	0	0.59[b]	10[b]	0.86
34	-0.03[b]	0	1.0[b]	62[b]	0.92
35	-0.02[c]	47[d]	-13.0[d]	40	0.35
36	-0.03[b]	59[c]	-16[c]	74[b]	0.84
37	-0.02[b]	59[c]	1.5[c]	44[b]	0.82
38	-0.007[d]	51[d]	-14[d]	23[b]	0.21
39	-0.04[b]	60[c]	-19[c]	82	0.92

[a]Energy use in these categories was small and the no-regression model produced satisfactory results. The value of r is set to zero in these industries.

[b]t-ratio > 3.5.

[c]t-ratio > 1.8.

[d]t-ratio > 1.

TABLE A.5 Regression Model Results for r(Q/FRB) for SIC 33 (t-ratios in parenthesis)

r	a	b	c	R^2	Period
-0.0049 (-6.8)	0	0.61 (5.4)	8.23 (512)	0.84	1969-82

APPENDIX B

INDUSTRIAL PRODUCTION INDEXES FOR THE NEPP-85 HIGH-ECONOMIC-GROWTH SCENARIO: CONSTRUCTION OF INDEXES BASED ON DRI REFERENCE AND PESSIMISTIC SCENARIOS

B.1 INTRODUCTION

Industrial production indexes are needed to prepare driver data for the Task Group B (TG-B) emissions model set of the National Acid Precipitation Assessment Program (NAPAP). Three major uses of national industrial production indexes are the following:

1. The Industrial Combustion Emissions (ICE) model requires industrial boiler fossil fuel demand (purchased) as an input. This needs to be provided for six industry groups and a residual category. The methodology used to construct boiler fuel use by industry is based on projections of industrial production.

2. The Industrial Sector Technology Use Model (ISTUM) is driven by indexes of physical output by industry group. These are constructed from indexes of industrial production.

3. The Industrial Volatile Organic Compounds (VOC) model is driven by composite indexes of industrial output that are designed to match VOC source categories.

The general approach used to regionalize the inputs to the ISTUM, ICE, and Industrial VOC models is described in a separate methodology document.[5]

Test runs of the TG-B emissions model set are being performed during Phase 1 to aid in model development and to help prepare the models for use by the task force. These test runs are based on the 1985 National Energy Policy Plan (NEPP-85), including its three economic growth scenarios: low, reference, and high. The low scenario corresponds to the DRI long-term pessimistic scenario, Fall 1984. The U.S. Department of Energy (DOE) reference scenario was simulated by DRI with its Macro Model. Hence for these two scenarios, DRI long-term (25-yr) macroeconomic simulations exist. (The forecast horizon is the year 2009.) Also, for these two scenarios the DOE Office of Policy, Planning, and Analysis contracted with DRI to prepare a consistent extension of these two scenarios to the year 2030.[6] DRI extended about 100 variables, including the set of industrial production indexes in its Macro Model. In summary, DRI projections for the low and reference scenarios are available for industrial production indexes.* These projections extend to the year 2030 and are broken down by two-digit SIC.

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*DRI economic model simulations corresponding to the NEPP-85 high scenario were not undertaken due to limited resources. Also it may have been felt that more analysis should be devoted to the reference and low scenarios, which are probably more likely economic growth scenarios.

The purpose of this appendix is to discuss the construction of indexes of industrial production for the NEPP-85 high-economic-growth scenario. Argonne assisted the DOE Offices of Policy, Planning, and Analysis (PPA) and Fossil Energy (FE) in performing this task. The process started with a high-scenario GNP projection from the NEPP-85 (see Table B.1). This GNP path is the basis for constructing industrial production indexes for the high scenario. The relationship between GNP and an index of industrial production had to be inferred from other DRI macroeconomic simulations. A separate relationship is estimated for each industry group (e.g., the chemical industry, SIC 28).

Two simple forecasting methods for constructing an industrial production projection in the high scenario are described. The methods are called the time-series (TS) and cross-section (CS) approaches. One lesson that has been learned in the forecasting field is that "consensus" forecasts systematically outperform individual forecasts. Therefore, it was proposed that the high scenario be constructed from a consensus forecast, that is, from the average of the projections based on the TS and CS methods. Note that this procedure allows more information to be incorporated into the projection than would be if either the TS or CS projection method was employed by itself.

B.2 REASONS FOR RECOMMENDING A CONSENSUS FORECAST

This section begins by considering the relationship between GNP and an index of industrial production (I_{FRB}). Fig. B.1 shows two functions. One has a slight downward curvature (concave), indicating an income (GNP) elasticity slightly less than one. The other function has an upward curvature (convex), indicating an income elasticity greater than one. A functional relationship between GNP and I_{FRB} can be estimated with values of GNP and I_{FRB} from a DRI macroeconomic simulation such as the DOE reference scenario. We call this method the time-series (TS) approach, since a time-series regression equation is estimated.

Other approaches can use information from both the DRI reference and pessimistic simulations. The cross-section (CS) approach makes a comparison between scenarios in any given year. For example, Figure B.2 shows GNP in the low (G_L) and reference (G_R) scenarios and the corresponding industrial production in the same year (I_L and I_R). By connecting these points (as shown in Fig. B.2) with a straight line, and by knowing GNP in the high scenario, the industrial production in the high scenario can be extrapolated. The CS approach assumes that differences between the low and reference scenarios can be extrapolated as differences between the reference and high scenarios.

The proposed approach undertakes a comparative analysis of the TS and CS scenarios. To begin the comparative analysis, consider the scenario in which the function shown in Fig. B.1 holds as a time-series relationship for all scenarios: pessimistic, reference, and high. That is, the TS income elasticities are the same in each scenario. Then the income elasticities used to project the high scenario could be obtained from reference scenario TS elasticity estimates. The high scenario could also be constructed using the CS method. The reason is that both points labeled L (low) and R (reference) in Fig. B.2 will also be on the curve shown in Figure B.1. The line connecting points

TABLE B.1 Real GNP Projections for Three NEPP-85 Scenarios

	Real GNP Levels by Scenario (10^9 1972 $)[a]			Average Annual Growth Rate (%) by Scenario		
Year	Low[b]	Reference[c]	High[d]	Low	Reference	High
Historical						
1980	1475	1475	1475	-	-	-
25-yr Projections						
1985	1710	1714	1721	3.00	3.05	3.13
1990	1914	2047	2104	2.28	3.61	4.10
1995	2108	2320	2422	1.95	2.54	2.85
2000	2309	2598	2783	1.84	2.29	2.82
2005	2544	2921	3200	1.96	2.37	2.83
2010	2811	3286	3685	2.02	2.38	2.86
Long-Term Extension						
2015	3039	3618	4196	1.57	1.94	2.63
2020	3254	3935	4630	1.38	1.69	1.99
2025	3487	4277	5083	1.39	1.68	1.88
2030	3736	4641	5543	1.39	1.65	1.75

[a]1972 dollars can be transformed to 1984 dollars for comparison with NEPP-85 by multiplying by the GNP implicit price deflator (estimated by DRI to be 2.23).

[b]Sources: DRI pessimistic long-term forecast (Autumn 1984) and DRI long-term extension to the year 2030 (Ref. 6).

[c]Sources: Special simulation of the DRI Macro Model corresponding to the DOE reference scenario for NEPP-85. (There are small differences between this GNP generated by the DRI Macro Model and GNP reported in the reference scenario of NEPP-85 because the DRI Macro Model does not track exactly the GNP in NEPP-85.) DRI also provided the long-term extension to the year 2030.

[d]The GNP projections to the year 2010 are taken from the NEPP-85 high scenario (and converted to 1972 dollars). DOE provided the GNP extension to 2030. Note that in the year 2030, the low and high projections form a symmetric difference of ±$900 x 10^9 around the reference scenario.

L and R and extended to the high GNP scenario will be close to the curve in Fig. B.1 provided that (1) the change in GNP from reference scenario to high scenario is not too large or (2) the curvature in the function is not too great (i.e., elasticity close to one). If these two conditions were both violated, then the TS approach would yield a more accurate high-scenario projection than the CS approach when the elasticities are the same across scenarios.

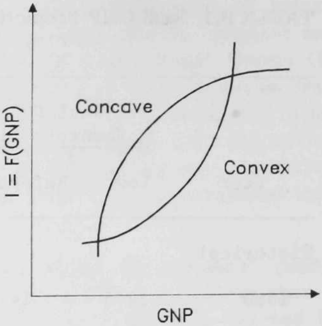

FIGURE B.1 Hypothetical Functional Relationship Between GNP and an Index of Industrial Production

To evaluate the TS and CS approaches, the TS elasticities were estimated over the period 1980-2009 for both the DRI reference and pessimistic scenarios.* A regression model using the logarithms of industrial production and GNP was estimated with a correction for first-order autocorrelation. The results are shown in Table B.2. We did not formally test the hypothesis that the income elasticity is constant across scenarios because it is difficult to obtain a valid test in the presence of omitted variables and autocorrelated residuals.

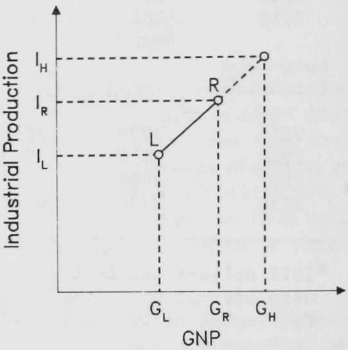

FIGURE B.2 Extrapolating the High-Scenario Index of Industrial Production with the Cross-Section Method

Nevertheless, an ad hoc comparison of the results was made and reported in the last column of Table B.2. For 12 scenarios, the income elasticity was about the same in both the reference and pessimistic scenarios. For three of these scenarios, the elasticities were close to one. For these 12 scenarios with similar TS elasticities across scenarios, the high scenario is about the same when constructed from either the TS or CS approach (as will be seen later in Table B.4).

*The time period includes both historical and projected data. Use of the historic data yielded more variation in the independent and dependent variables, which is felt to improve statistical identification of the income elasticity. It should be noted that all statistical questions that may arise from the use of constructed data are ignored. The main statistical problem is the lack of independence between the explanatory variables and the error term in the regression because they will both depend on omitted variables.

TABLE B.2 Income Elasticity Estimates of Industrial Production Implicit in DRI Forecasts[a]

	Reference Scenario (R)		Pessimistic Scenario (L)		Comparison of Elasticities	
SIC	Elasticity	R^2	Elasticity	R^2	R > L[b]	Size[c]
20	0.794	0.99	0.827	0.99		<1
21	0.481	0.86	0.398	0.78		<1
22	0.858	0.96	0.617	0.92	*	
23	0.708	0.84	0.510	0.57	*	
24	0.957	0.88	0.815	0.85	*	
25	1.248	0.96	1.107	0.95	*	
26	0.956	0.99	1.026	0.99		≈1
27	0.915	0.98	0.993	0.98		≈1
28	1.626	0.99	1.706	0.99		>1
29	0.450	0.87	0.374	0.69		<1
30	1.877	0.99	2.021	0.98		>1
31[d]	-0.153	0.14	-0.960	0.68		
32	1.073	0.98	1.101	0.98		≈1
33	1.090	0.88	0.830	0.84	*	
34	1.385	0.97	1.080	0.89	*	
35	1.219	0.97	1.150	0.96		>1
36	1.719	0.95	1.659	0.98		>1
37	1.580	0.97	1.671	0.98		>1
38	1.404	0.93	1.368	0.99		>1
39	1.601	0.98	1.489	0.97	*	

[a]Estimation period 1980-2009, using a constant elasticity model.

[b]Scenarios where reference-scenario elasticity appears to be significantly greater than the low-scenario elasticity.

[c]Approximate magnitude of elasticities where reference and low elasticities are close.

[d]Note that the leather industry uses insignificant amounts of energy, so that the poor fit and negative elasticity are not particularly important.

Therefore, the choice of the TS or CS approach only matters when the difference between elasticities shown in Table B.2 is large. Specifically, if the TS elasticity in the reference scenario is greater (less) than the TS elasticity in the pessimistic scenario, then the CS method would tend to yield a higher (lower) high-scenario projection than would the TS method. This result is illustrated in Fig. B.3. There are seven applicable scenarios in which the reference-scenario TS elasticity is greater than the low-scenario TS elasticity, as shown in Table B.2. For these industry groups, it is thought that a consensus forecast, averaging the TS and CS methods, yields the best result. There is validity to the CS approach: if the income elasticity is higher in the reference scenario than in the low scenario, then it can be expected to be even higher yet in the high scenario. However, when extrapolating to the high scenario, one must take care not to exaggerate the income elasticity.

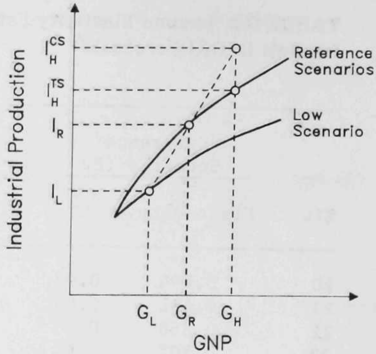

FIGURE B.3 Situation Where Industrial Production for the High Scenario is Greater When Constructed with the Cross-Section Method Than with the Time-Series Method

As a final point, note that the CS approach uses information from only one year to construct the high scenario for that year. Because of the lag structure in macroeconomic models, GNP and industrial production are not always in phase. The CS approach will tend to exaggerate any out-of-phase cyclical variation in constructing industrial production for the high scenario. The TS approach is not as sensitive to annual fluctuations.

B.3 ESTIMATION AND PROJECTION TECHNIQUES

In the CS method, the projection in the high scenario is constructed with a simple algebraic relationship, applied in each year t:

$$I_H^{CS}(t) = I_R(t) + SLOPE_{RL}(t)\left[G_H(t) - G_R(t)\right] \tag{B.1}$$

where

$$SLOPE_{RL}(t) = \frac{I_R(t) - I_L(t)}{G_R(t) - G_L(t)}$$

In the TS method, a piecewise constant elasticity function is used:

$$I_H^{TS}(t) = \begin{cases} A_1\, G_H^{\beta_1}(t), & \text{for } 1985 \le t \le 1990 \\ A_2\, G_H^{\beta_2}(t), & \text{for } 1991 \le t \le 2010 \\ A_3\, G_H^{\beta_3}(t), & \text{for } 2011 \le t \le 2030 \end{cases} \tag{B.2}$$

Hence, distinct elasticities are allowed in three different time periods. The estimates for elasticities β by period for the reference scenario are shown in Table B.3.* In the 1980s the DRI forecasts show some "catch up" in some industries such as primary metals (SIC 33). That is, the industrial growth relative to GNP may be higher in the 1980s than in later periods. The income elasticity β is a measure of this industrial growth rate relative to GNP. Hence for SIC 33, the value of β in the 1985-90 period is greater than in subsequent periods. Also, the period after 2010 is treated separately because the long-term extension provided by DRI for this period in some scenarios shows significantly slower growth in an industry relative to GNP. Several examples of this (i.e., low elasticities in the third period) can be found in Table B.3, notably SICs 24, 29, and 33.

The consensus forecast $I_H(t)$ is the average of $I_H^{CS}(t)$ and $I_H^{TS}(t)$. One further restriction was added:

$$I_H(t) \geq I_R(t)$$

This constraint is binding for some industries in 1985 due to the cyclical behavior of the DRI Macro Model, which yields slightly higher industrial production in 1985 for the pessimistic scenario than for the reference scenario.

B.4 DISCUSSION OF RESULTS

The results for the TS, CS, and consensus projections are shown in Table B.4 for SICs 20 through 39 by 5-yr increments. The TS and CS projections can be compared. Also, the consensus projection for the high scenario can be compared with the low and reference scenarios.

It has been contended that if the reference and pessimistic scenarios had about the same elasticities (which is the case, as shown in Table B.2, for SICs 20, 21, 26, 27, 28, 29, 30, 32, 35, 36, 37, and 38), then the CS and TS approaches will yield about the same high-scenario projection. The results generally support this conclusion. For the situations where the reference scenario shows a higher elasticity than the pessimistic

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*Restricted least-squares estimation was used with parameter restrictions, ensuring continuous projections in 1991 and 2011 where the periods join.

TABLE B.3 Income (GNP) Time-Series Elasticities: Reference Scenario[a]

	Period		
SIC	1985-1990	1991-2010	2011-2030
20	0.783	0.842	0.912
21	0.440	0.666	0.922
22	0.947	0.729	0.491
23	0.538	0.669	0.843
24	1.102	0.661	0.159
25	0.998	0.987	0.608
26	0.976	0.907	0.838
27	0.729	0.816	0.668
28	1.731	1.697	1.816
29	0.571	0.364	0.106
30	1.763	1.676	1.375
31	0.754	-0.584	-1.027
32	1.152	0.944	0.679
33	1.210	0.776	0.016
34	1.115	1.150	0.922
35	2.227	1.341	0.747
36	1.778	1.251	0.751
37	1.241	1.084	0.530
38	2.094	1.509	1.363
39	1.410	0.988	0.870

[a] $R^2 = 0.99$ for all SICs except SIC 31, for which $R^2 = 0.98$.

scenario (i.e., SICs 22, 23, 24, 25, 33, 34, and 39), the CS method yields a higher projection than the TS method. The consensus forecast, which takes into account both CS and TS information, appears reasonable. The leather industry, SIC 31, is peculiar because it declines over time and hence is negatively correlated with GNP. However, the consensus forecast for this industry still appears reasonable and usable for our purposes. Also, this industry is a very small energy user and does not merit special attention.

In comparing industrial production for the low, reference, and high scenarios, the underlying GNP for these scenarios should be kept in mind. In the 1990s the GNP gap between the low and reference scenarios is greater than the gap between the reference and high scenarios. In fact, not until the year 2005 are the differences in GNP

TABLE B.4 Projections of Industrial Production Indexes by Industry Group, Scenario, and Method

				High Scenario		
SIC	Year	Low Scenario	Ref. Scenario	Con-sensus	Time Series	Cross-Section
20	1980	1.496	1.496	1.496	-	-
	1985	1.702	1.692	1.692	1.684	1.676
	1990	1.891	1.919	1.951	1.971	1.931
	1995	2.072	2.156	2.208	2.219	2.197
	2000	2.213	2.358	2.473	2.494	2.451
	2005	2.377	2.590	2.777	2.806	2.747
	2010	2.589	2.860	3.124	3.160	3.088
	2015	2.745	3.110	3.516	3.557	3.475
	2020	2.879	3.356	3.867	3.891	3.843
	2025	3.023	3.620	4.233	4.236	4.230
	2030	3.174	3.902	4.606	4.585	4.627
21	1980	1.198	1.198	1.198	-	-
	1985	1.185	1.181	1.181	1.185	1.175
	1990	1.242	1.290	1.303	1.295	1.311
	1995	1.291	1.385	1.426	1.422	1.430
	2000	1.349	1.481	1.563	1.560	1.566
	2005	1.438	1.603	1.718	1.712	1.725
	2010	1.532	1.718	1.877	1.881	1.874
	2015	1.617	1.852	2.103	2.120	2.087
	2020	1.712	2.000	2.308	2.321	2.294
	2025	1.812	2.159	2.522	2.530	2.513
	2030	1.919	2.332	2.742	2.740	2.743
22	1980	1.386	1.386	1.386	-	-
	1985	1.504	1.497	1.520	1.555	1.486
	1990	1.656	1.866	1.918	1.880	1.956
	1995	1.675	1.966	2.095	2.084	2.107
	2000	1.782	2.177	2.368	2.306	2.431
	2005	1.893	2.427	2.688	2.553	2.822
	2010	1.985	2.633	3.004	2.830	3.177
	2015	2.030	2.795	3.288	3.016	3.560
	2020	2.047	2.917	3.485	3.166	3.805
	2025	2.067	3.041	3.675	3.314	4.036
	2030	2.087	3.163	3.846	3.458	4.235
23	1980	1.269	1.269	1.269	-	-
	1985	1.399	1.391	1.413	1.447	1.378
	1990	1.499	1.633	1.652	1.613	1.691
	1995	1.493	1.704	1.789	1.772	1.806
	2000	1.550	1.841	1.986	1.944	2.028

TABLE B.4 (Cont'd)

				High Scenario		
SIC	Year	Low Scenario	Ref. Scenario	Con-sensus	Time Series	Cross-Section
	2005	1.599	1.976	2.195	2.135	2.255
	2010	1.637	2.166	2.478	2.346	2.610
	2015	1.604	2.335	2.842	2.618	3.066
	2020	1.535	2.495	3.160	2.844	3.475
	2025	1.473	2.666	3.481	3.077	3.884
	2030	1.413	2.849	3.795	3.310	4.279
24	1980	1.194	1.194	1.194	-	-
	1985	1.436	1.454	1.495	1.508	1.483
	1990	1.621	1.839	1.907	1.882	1.933
	1995	1.677	1.975	2.092	2.065	2.119
	2000	1.780	2.139	2.317	2.264	2.369
	2005	1.919	2.365	2.589	2.483	2.695
	2010	2.042	2.606	2.903	2.726	3.080
	2015	2.086	2.712	3.060	2.783	3.338
	2020	2.089	2.751	3.127	2.827	3.427
	2025	2.096	2.787	3.181	2.869	3.493
	2030	2.102	2.815	3.217	2.909	3.525
25	1980	1.499	1.499	1.499	-	-
	1985	1.998	2.033	2.097	2.104	2.089
	1990	2.146	2.513	2.621	2.572	2.671
	1995	2.282	2.779	2.987	2.955	3.019
	2000	2.519	3.142	3.466	3.389	3.542
	2005	2.836	3.625	4.049	3.890	4.208
	2010	3.104	4.067	4.674	4.472	4.876
	2015	3.308	4.396	5.161	4.839	5.483
	2020	3.471	4.637	5.483	5.138	5.828
	2025	3.649	4.885	5.793	5.438	6.147
	2030	3.834	5.131	6.077	5.732	6.423
26	1980	1.511	1.511	1.511	-	-
	1985	1.807	1.796	1.796	1.798	1.779
	1990	2.036	2.107	2.163	2.188	2.138
	1995	2.253	2.399	2.478	2.487	2.470
	2000	2.451	2.653	2.802	2.821	2.783
	2005	2.674	2.950	3.178	3.202	3.154
	2010	2.957	3.293	3.607	3.639	3.575
	2015	3.159	3.582	4.031	4.057	4.005
	2020	3.327	3.844	4.389	4.406	4.372
	2025	3.511	4.122	4.755	4.764	4.746
	2030	3.702	4.412	5.121	5.123	5.119

TABLE B.4 (Cont'd)

				High Scenario		
SIC	Year	Low Scenario	Ref. Scenario	Con-sensus	Time Series	Cross-Section
27	1980	1.395	1.395	1.395	-	-
	1985	1.734	1.737	1.750	1.758	1.742
	1990	1.925	1.991	2.027	2.035	2.019
	1995	2.092	2.195	2.264	2.283	2.245
	2000	2.260	2.412	2.533	2.557	2.510
	2005	2.463	2.676	2.849	2.865	2.833
	2010	2.702	2.948	3.185	3.215	3.155
	2015	2.859	3.167	3.490	3.506	3.475
	2020	2.979	3.353	3.740	3.744	3.735
	2025	3.109	3.548	3.991	3.985	3.996
	2030	3.243	3.747	4.236	4.223	4.249
28	1980	2.072	2.072	2.072	-	-
	1985	2.478	2.467	2.467	2.463	2.450
	1990	3.048	3.310	3.455	3.488	3.423
	1995	3.695	4.141	4.393	4.429	4.357
	2000	4.326	4.998	5.518	5.607	5.429
	2005	5.064	6.071	6.961	7.106	6.815
	2010	6.029	7.389	8.780	9.029	8.532
	2015	6.937	8.746	10.992	11.430	10.554
	2020	7.863	10.179	13.105	13.667	12.544
	2025	8.929	11.839	15.501	16.191	14.811
	2030	10.133	13.740	18.140	18.949	17.332
29	1980	1.331	1.331	1.331	-	-
	1985	1.321	1.316	1.332	1.357	1.308
	1990	1.448	1.496	1.519	1.521	1.517
	1995	1.488	1.573	1.608	1.601	1.614
	2000	1.524	1.638	1.698	1.684	1.711
	2005	1.558	1.712	1.799	1.772	1.826
	2010	1.615	1.820	1.929	1.865	1.992
	2015	1.627	1.860	1.992	1.891	2.093
	2020	1.619	1.877	2.026	1.911	2.140
	2025	1.614	1.894	2.055	1.930	2.180
	2030	1.608	1.907	2.076	1.948	2.205
30	1980	2.557	2.557	2.557	-	-
	1985	3.695	3.674	3.703	3.765	3.641
	1990	4.688	5.112	5.330	5.366	5.294
	1995	5.654	6.287	6.694	6.794	6.593
	2000	6.590	7.580	8.396	8.576	8.216
	2005	7.780	9.390	10.709	10.838	10.580
	2010	9.445	11.499	13.478	13.731	13.225

TABLE B.4 (Cont'd)

SIC	Year	Low Scenario	Ref. Scenario	High Scenario Con-sensus	High Scenario Time Series	High Scenario Cross-Section
	2015	10.604	13.331	16.236	16.415	16.056
	2020	11.536	14.987	18.652	18.794	18.511
	2025	12.599	16.823	21.252	21.367	21.137
	2030	13.743	18.813	23.966	24.069	23.862
31	1980	0.700	0.700	0.700	-	-
	1985	0.632	0.622	0.622	0.609	0.606
	1990	0.605	0.692	0.719	0.708	0.729
	1995	0.519	0.647	0.681	0.652	0.709
	2000	0.485	0.638	0.669	0.602	0.736
	2005	0.410	0.605	0.652	0.555	0.749
	2010	0.325	0.553	0.628	0.511	0.745
	2015	0.275	0.516	0.602	0.447	0.757
	2020	0.228	0.475	0.566	0.404	0.727
	2025	0.190	0.437	0.528	0.367	0.689
	2030	0.158	0.401	0.489	0.336	0.643
32	1980	1.479	1.479	1.479	-	-
	1985	1.651	1.657	1.679	1.692	1.667
	1990	1.893	2.064	2.135	2.133	2.138
	1995	2.073	2.310	2.430	2.436	2.425
	2000	2.296	2.605	2.791	2.778	2.803
	2005	2.547	2.955	3.213	3.169	3.257
	2010	2.809	3.288	3.656	3.621	3.690
	2015	3.002	3.559	4.035	3.955	4.116
	2020	3.155	3.775	4.318	4.228	4.408
	2025	3.322	4.000	4.599	4.505	4.692
	2030	3.496	4.228	4.868	4.778	4.957
33	1980	1.022	1.022	1.022	-	-
	1985	1.073	1.102	1.153	1.159	1.148
	1990	1.183	1.421	1.500	1.477	1.523
	1995	1.240	1.552	1.675	1.648	1.703
	2000	1.321	1.738	1.921	1.835	2.006
	2005	1.428	1.956	2.196	2.045	2.346
	2010	1.511	2.174	2.507	2.282	2.731
	2015	1.536	2.259	2.634	2.287	2.982
	2020	1.524	2.271	2.662	2.291	3.034
	2025	1.517	2.279	2.676	2.294	3.057
	2030	1.508	2.278	2.671	2.297	3.045

TABLE B.4 (Cont'd)

				High Scenario		
SIC	Year	Low Scenario	Ref. Scenario	Con- sensus	Time Series	Cross- Section
34	1980	1.341	1.341	1.341	-	-
	1985	1.465	1.493	1.544	1.551	1.538
	1990	1.622	1.907	1.985	1.940	2.030
	1995	1.777	2.122	2.285	2.281	2.289
	2000	2.011	2.469	2.720	2.676	2.763
	2005	2.295	2.892	3.238	3.142	3.333
	2010	2.599	3.265	3.760	3.696	3.825
	2015	2.844	3.609	4.270	4.166	4.374
	2020	3.076	3.910	4.662	4.562	4.762
	2025	3.333	4.232	5.061	4.972	5.150
	2030	3.610	4.568	5.454	5.386	5.522
35	1980	1.628	1.628	1.628	-	-
	1985	1.967	2.013	2.068	2.050	2.086
	1990	2.389	2.941	3.193	3.207	3.179
	1995	2.852	3.648	3.953	3.873	4.033
	2000	3.332	4.332	4.820	4.666	4.974
	2005	3.827	5.067	5.805	5.626	5.984
	2010	4.493	6.010	7.041	6.798	7.285
	2015	5.033	6.669	7.897	7.491	8.304
	2020	5.517	7.116	8.406	8.062	8.749
	2025	6.063	7.579	8.886	8.645	9.127
	2030	6.657	8.033	9.313	9.223	9.403
36	1980	1.728	1.728	1.728	-	-
	1985	2.376	2.366	2.366	2.377	2.350
	1990	2.816	3.204	3.384	3.398	3.371
	1995	3.169	3.779	4.063	4.052	4.074
	2000	3.722	4.487	4.900	4.821	4.978
	2005	4.374	5.264	5.832	5.741	5.922
	2010	5.034	6.092	6.915	6.849	6.981
	2015	5.569	6.726	7.717	7.551	7.882
	2020	6.013	7.176	8.247	8.131	8.364
	2025	6.511	7.644	8.761	8.721	8.801
	2030	7.044	8.108	9.238	9.308	9.168
37	1980	1.167	1.167	1.167	-	-
	1985	1.474	1.514	1.578	1.578	1.578
	1990	1.660	1.953	2.052	2.025	2.079
	1995	1.836	2.202	2.369	2.358	2.379
	2000	2.090	2.532	2.779	2.742	2.816
	2005	2.377	2.959	3.289	3.189	3.389
	2010	2.696	3.367	3.824	3.717	3.931

TABLE B.4 (Cont'd)

				High Scenario		
SIC	Year	Low Scenario	Ref. Scenario	Con-sensus	Time Series	Cross-Section
	2015	2.930	3.647	4.173	3.982	4.364
	2020	3.120	3.826	4.371	4.195	4.547
	2025	3.330	4.009	4.555	4.408	4.702
	2030	3.551	4.184	4.715	4.615	4.814
38	1980	1.711	1.711	1.711	-	-
	1985	1.866	1.898	1.942	1.935	1.949
	1990	2.265	2.749	2.952	2.948	2.957
	1995	2.679	3.419	3.711	3.645	3.777
	2000	3.111	4.077	4.597	4.496	4.697
	2005	3.605	4.849	5.660	5.551	5.769
	2010	4.224	5.827	7.021	6.868	7.174
	2015	4.852	6.702	8.375	8.199	8.551
	2020	5.521	7.513	9.461	9.376	9.547
	2025	6.290	8.412	10.614	10.648	10.579
	2030	7.164	9.389	11.794	11.983	11.605
39	1980	1.484	1.484	1.484	-	-
	1985	1.573	1.589	1.614	1.613	1.614
	1990	1.775	2.407	2.153	2.142	2.164
	1995	1.935	2.345	2.502	2.461	2.543
	2000	2.122	2.641	2.899	2.823	2.974
	2005	2.320	2.980	3.354	3.241	3.468
	2010	2.522	3.348	3.884	3.726	4.042
	2015	2.706	3.666	4.399	4.172	4.625
	2020	2.878	3.944	4.789	4.545	5.033
	2025	3.064	4.240	5.185	4.930	5.441
	2030	3.261	4.549	5.574	5.316	5.832

approximately symmetric around the reference scenario. Hence, for the beginning half of the forecast period, one should typically observe a larger gap in industrial production between the low and reference scenarios than between the reference and high scenarios. For industries where the pessimistic case has a lower TS elasticity than in the reference scenario, there may develop an even wider gap between the reference and low scenario industrial production indexes.

These points are illustrated with an example for SIC 33, primary metals. In 1990, we have the following data from Tables B.1 and B.4:

$$G_R - G_L = 133$$

$$G_H - G_R = 57$$

$$I_R - I_L = 0.238$$

$$I_H^{CS} - I_R = \frac{0.238}{133} \times 57 = 0.102$$

In this example, the gaps in industrial production (i.e., 0.238 versus 0.102) are due solely to the difference in GNP levels (i.e., 133 versus 57). However, it is important to notice that the low scenario has a lower income elasticity than the reference scenario. This lower elasticity means that primary metals output is growing slower relative to GNP in the low scenario than it is in the reference scenario. Therefore, primary metals will be growing faster relative to GNP in the high scenario than in the reference scenario. However, we recommend being cautious about increasing too much the rate at which an industry like primary metals is growing relative to GNP. This caution is implemented by averaging the CS and TS methods. With the TS method, industrial production grows at the same rate relative to GNP in the high scenario as it does in the reference scenario. Numerically, the results from Table B.4 are

$$I_H^{TS} - I_R = 0.056$$

$$I_H^{CONSENSUS} - I_R = 0.079$$

For most industries, the TS and CS methods yield about the same results, as shown in Table B.4. For example, in SIC 20, the food industry, the high-scenario TS and CS projections in the year 2030 differ by less than 1%.

B.5 SUMMARY AND APPLICATIONS

This appendix presents a methodology for constructing indexes of industrial production corresponding to the NEPP-85 high scenario. The resulting projections shown in Table B.4 appear reasonable. These projections have been used in preparing the ICE model driver data. For the ICE model, the driver data are not very sensitive to these industrial production indexes because the NEPP-85 provides a control total for industrial fossil fuel use. The industrial production indexes only serve to distribute the NEPP-85 control total among two-digit SIC industry groups.

These projections of industrial production indexes also drive the ISTUM and Industrial VOC models.* For these models, the emissions projections are sensitive to the industrial production indexes because there is no control total as in the ICE model driver data.

The approach presented here is to construct a high-scenario projection by combining the results from two methods: (1) a time-series (TS) method using income elasticities derived from the reference scenario and (2) a cross-section (CS) method based on a comparison of the low and reference DRI scenarios in any given year with a linear extrapolation to the high scenario. The projections derived with methods 1 and 2 are simply averaged to obtain a consensus forecast. There are several reasons for averaging the results of two methods. Each method uses different information, so the consensus incorporates both TS and CS information. This avoids possible extreme forecasts that might result from a pure TS or CS application. For most industries, the TS and CS approaches yield about the same high-scenario projections. However, for some industries, the CS method yields a higher projection for reasons discussed previously. For these industries, the consensus forecast appears reasonable. It should be noted, however, that resources are not available to perform case studies on individual industries. Case studies and industry-specific models could potentially improve the forecasts. In the absence of case studies, the consensus forecast method proposed here provides a systematic approach that yields reasonable results.

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*Composite indexes for 101 VOC categories are constructed from detailed industrial forecasts for the reference and pessimistic scenarios. These 101 indexes were used directly to construct the high scenario in a procedure identical to the one outlined for the FRB indexes.

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